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Pedagogical Content Knowledge (PCK) Change and Professional Development for Educators: An Assessment of a Master's in Chemistry Program for High School Science Teachers

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PEDAGOGICAL CONTENT KNOWLEDGE (PCK) CHANGE AND PROFESSIONAL DEVELOPMENT FOR EDUCATORS: AN ASSESSMENT OF A MASTER'S IN CHEMISTRY PROGRAM FOR HIGH SCHOOL SCIENCE TEACHERS

BY

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Mary Charlotte Bautista

This dissertation is approved as a creditable and independent investigation by a candidate for the Doctor of Philosophy degree and is acceptable for meeting the dissertation requirements for this degree. Acceptance of this does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Matthew Miller
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This dissertation is dedicated to my husband, who has been my constant supporter through this program. Thank you for your encouragement, patience, and kindness. I am so grateful for you and all you have done to make completing this degree possible. I could not have done this without you.

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I could not have completed this work without support from my husband, my family, and God.

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ABBREVIATIONS

ASCI	Attitudes toward Subject of Chemistry Inventory
CB1	Codebook 1
CB2	Codebook 2
CB3	Codebook 3
CB4	Codebook 4
CoRe	Content Representation
GTA	graduate teaching assistant
KoA	knowledge of assessment
KoCO	knowledge of curriculum organization
KoG	knowledge of goals
KoR	knowledge of resources
KoSc	knowledge of science
KoSt	knowledge of students
KoT	knowledge of teaching
PCK	pedagogical content knowledge

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ABSTRACT

PEDAGOGICAL CONTENT KNOWLEDGE (PCK) CHANGE AND PROFESSIONAL DEVELOPMENT FOR EDUCATORS: AN ASSESSMENT OF A MASTER'S IN CHEMISTRY PROGRAM FOR HIGH SCHOOL SCIENCE TEACHERS

MARY CHARLOTTE BAUTISTA

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The M.S. Chemistry – Chemical Education Specialization program at South Dakota State University provides in-depth general chemistry coursework to in-service high school science teachers in a virtual format. The goal of the program is for the teachers enrolled to become more effective teachers while gaining content knowledge in chemistry; in essence, to increase their pedagogical content knowledge (PCK). The aim of this study is to follow participants through their experience in this program in order to understand how the program's requirements enhance its participants' teaching and learning. A narrative framework follows one participant through their two-year experience in the program, using virtual teaching observations, chemistry content exams, and individual interviews. Surveys and course assignments were analyzed to determine pedagogical change exhibited by science teachers and provide details as to why their experience in the program may have yielded PCK change. Modules have been implemented in content courses to determine changes in PCK through the teachers' development of chemistry content knowledge. An on-campus summer research experience documents teachers' experiences in a research environment and how it informs development of classroom activities. Teachers demonstrated improved quantity and quality of PCK through MS

program core courses, including the campus summer experiences. Participants also experienced professional development through the MS program. Interactions between MS program participants supported positive PCK and professional development change.

CHAPTER 1: INTRODUCTION

Researcher Background

Prior to entering the PhD program at South Dakota State University (SDSU), I completed a master's degree in chemistry. While in my first semester of graduate school, I learned about chemical education research and decided to pursue my thesis research in this sub-discipline. My MS research project involved working with pre-service teachers and learning about how they planned to integrate complex scientific issues into their teaching. That research focused on pre-service teachers and their hopes and goals for entering the teaching field. Upon graduation, I knew I wanted to continue working with teachers through research. Before graduate school, I was interested in becoming a teacher myself; however, when my own career goals changed, the desire to be involved with the teaching profession in some capacity remained. After conducting a study with pre-service teachers for my thesis, I realized I had a continued interest in what/how teachers decide to teach and why. This interest extended to teachers at all stages in their careers, including pre-service and in-service.

After deciding to pursue a PhD, I wanted to continue on with chemical education research. While discussing potential projects for my PhD research, the idea of evaluating the MS program was most enticing due to its engagement with teachers. In addition to involving teachers, this project also focused on assessing the effectiveness of an academic program. I decided to go forward with this project, which allowed me to collaborate with in-service science teachers who were working toward graduate degrees in chemistry. By evaluating this MS program, I could measure the impact it has had on the teachers, which in turn would impact instruction in their own classrooms.

Furthermore, this MS program is able to reach K-12 science students through their interactions with teachers.

By conducting this research, I have learned a great deal about how this MS program is organized and have gained a deeper understanding of why these specific courses and requirements were developed. In addition to learning about the MS program from the institution's perspective, I observed what the experience is like from a participant's point of view. Through my research, I gained experience with evaluating a formal graduate program for teachers. In the future, I would be able to evaluate other university-level courses and programs based on my experience with this work.

Teacher Knowledge & Impact

In general, teachers create two important types of knowledge: content and pedagogy. Content knowledge is constructed through courses and other experiences in a scientific discipline. Pedagogical knowledge is constructed during experiences in teacher preparation programs and experience in the classroom. After obtaining certification, qualified teachers can teach within their licensed discipline(s) in a classroom setting.

However, teachers have additional expertise beyond the content and pedagogical knowledge. They also know how to reach diverse learners and they gain an understanding of the complex nature of the setting. Knowledge of students and context are also important aspects of teacher knowledge. Lee S. Shulman defined pedagogical content knowledge (PCK) as a professional knowledge base exclusively for educators.[1] He wrote that PCK "represents the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction."[1] PCK can be broken down into several components, each component describing a unique category of knowledge that teachers possess. This philosophy of teacher knowledge was the basis of my work in this project.

My personal attitude toward educators is that they have a valuable impact on the students they teach. This impact is a direct result of their development level in the various knowledge bases described above, which can influence students' knowledge and attitudes toward the subject matter and learning in general. Along with teaching may come meaningful student-teacher relationships akin to mentorships. K-12 teachers reach students at critical stages of a person's development and these interactions may have a lasting impact.

MS Program Purpose

The MS Chemistry – Chemical Education Specialization at South Dakota State University (to be referred to throughout as the MS program) was designed with in-service teachers in mind. This MS program is not a teaching certification program; instead, teachers with a valid teaching license in a scientific discipline are able to gain chemistry content knowledge in the context of teaching Advanced Placement (AP) Chemistry topics.[2] This means that the content is geared toward general chemistry topics that are generally applicable to an AP or Honors chemistry level and the coursework involves assignments that relate to teachers' work in the classroom. The MS program's content courses refresh and expand teachers' prior chemistry knowledge and fill gaps in their undergraduate education by introducing new concepts at the graduate level.

My role in this research was as a participant observer. As a graduate teaching assistant (GTA) for the courses in the MS program, I graded homework sets, discussion forums, modules, and various other assignments. In this role, I was involved with the day-to-day procedures of each course. Through this work, I was best able to insert myself as a researcher into their experience as MS program participants. I was able to simultaneously learn about the structure and content of the MS program's courses and observe what my narrative participant and the general MS program population were sharing and learning through the program's requirements.

Purpose of the Study

The MS program has been offering courses for over a decade, but its impact has not been formally researched. This study fills this gap and allows for an investigation into the MS program's impact on teachers' PCK while also gaining valuable feedback on the MS program itself and how it can be improved for future participants. Through this study, I was better able to understand how teachers were transformed through the MS program and how they became better teachers in the process. The purpose of this project was to evaluate the effectiveness of the MS program. I wanted to know how teachers' content knowledge was impacted by the chemistry content courses, how participants learned to evaluate their own teaching, and how these knowledge bases came together to inform their PCK.

MS Program Background

The MS program developed out of an idea Dr. Matthew Miller had when he arrived at South Dakota State University related to his personal experiences. When he decided to pursue graduate work in chemistry, he was a high school science teacher. At the time, the local universities offered graduate courses related to a Master's in Chemistry during the day and only in the Fall and Spring semesters. Going to graduate school would necessitate leaving teaching for the duration of his graduate studies. Creating an online chemistry graduate program for in-service teachers would solve this issue; teachers would be able to remain in the classroom while working toward a master's degree in chemistry. At the time, online programs weren't prevalent, but a grant from the Provost's Office allowed Dr. Miller to travel around South Dakota to interview teachers at their respective schools in the Spring of 2005. Those involved in this preliminary survey expressed interest but also trepidation at how long they would be required to be on campus, specifically during the summer. These teacher discussions were used in program design development, which was then discussed among SDSU's chemical education faculty and the Chemistry & Biochemistry department head. Through these discussions, the MS program and accompanying graduate courses were created. It took a few years to get formal approval for the MS program from the university and South Dakota Board of Regents, but the department began offering courses for the MS program in the Fall 2008 semester.

Program in Focus

The MS program allows in-service science teachers to earn a chemistry graduate degree while continuing to teach full-time. The MS program coursework includes chemistry content courses (75% of the credits are counted as content-based courses), a pedagogical course (one 3-credit course), and action research courses (a total of 5 credits) through which participants develop and implement a research project in their own classrooms. All course delivery is virtual, except for two, two-week summer sessions on campus in Brookings, SD. The MS program was originally designed to be completed in two and a half years, but some teachers have matriculated in two years while others have extended the time in order to reduce their course workload while they teach. Due to its virtual format, the MS program has a wide reach: approximately 100 teachers have been involved in the MS program since 2008, representing 31 states and China at their time of participation. A map of the United States displays a geographical representation of teachers at the time of their study in the MS program (Figure 1).

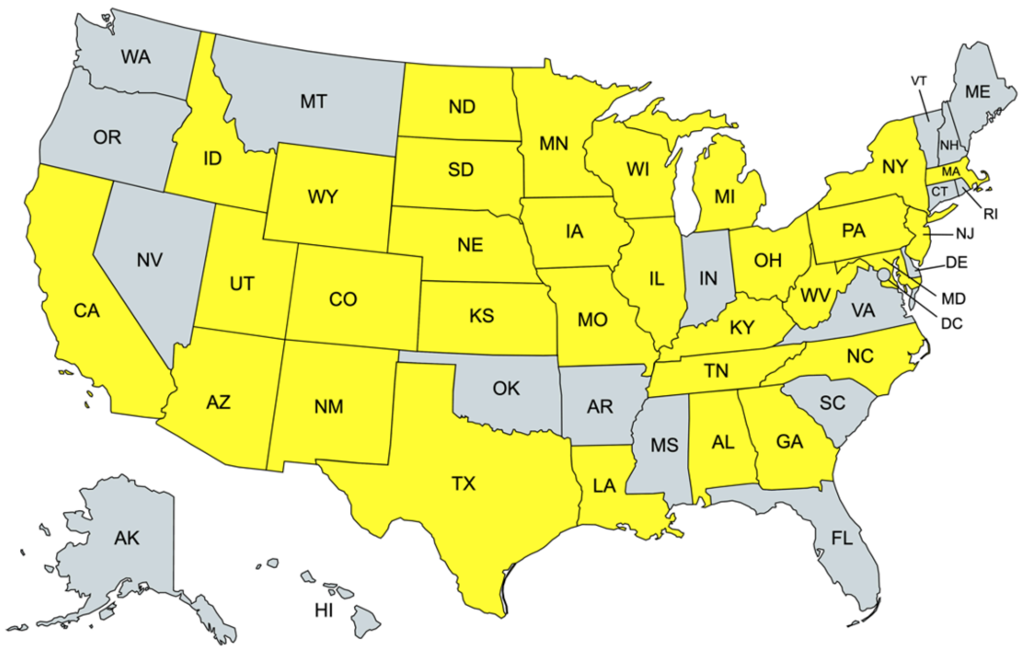


Figure 1. Map of MS program participant geographic distribution as of Summer 2023, with represented states highlighted in yellow.

MS Program & Study Importance

All participants in the MS program are in-service science teachers who desire to expand their chemistry content knowledge while staying in the classroom. The MS program has always had the intent of keeping teachers in the field while providing an opportunity for professional development. There is currently a shortage of science teachers in secondary education.[3, 4] It is essential that teachers be encouraged to remain on the teaching career path. As mentioned previously, K-12 teachers reach students at critical stages of a person's development and experienced teachers are needed to successfully meet these needs. Students who attend schools that have poor teacher retention and staffing shortages experience lower achievement in STEM (Science, Technology, Engineering, and Mathematics) disciplines.[4] This MS program aims to facilitate teacher development, transform the teachers into more effective educators, and retain teachers in the field. One purpose of this project was to assess the effectiveness and quality of the MS program in terms of its participants' development. Therefore, this project was essential to better understand whether or not this MS program adequately supports teachers' professional development, how the MS program should be improved for future participants, and what knowledge teachers took away from this MS program that allowed them to develop into more effective educators.

Interpretive Framework & Approach to Inquiry

For this project, I operated under a social constructivist framework. Constructivism is an epistemological approach that assumes that knowledge is constructed in the mind of the learner.[5] Constructivists believe that knowing is an adaptive activity.[6] There is no single truth or method for creating knowledge, as it is constructed by the individual and relates to one's own experiences and prior knowledge.

Various types of constructivism exist based on specific philosophical interpretations of how and why knowledge is constructed. One type of constructivist theory is social constructivism. Social constructivists place value on the collaborative nature of learning, focusing on how knowledge is constructed as a result of learning together with peers.

This form of constructivism is a good representation of the MS program because it helps describe the teacher learning that may be occurring. Teachers come into the MS program with existing knowledge, in both their chemistry content knowledge and their pedagogical knowledge. Teachers construct new knowledge that builds on or modifies conceptions of existing knowledge, both individually and in community with one another. As part of my research I sought to understand how this MS program allowed teachers to construct knowledge, if at all, and how the MS program and its courses supported and expanded on teachers' existing knowledge.

In order to learn more about participants' experiences in the MS program, I decided to use a case study approach following incoming teachers in the MS program throughout their two-year experience in the MS program. The MS program has had a relatively stable enrollment of between 8-10 new students each year. These new students were invited to participate in the study; however, due to a low response to the invitation (only one participant agreed to participate in a case study) the number of participants no longer fit the criteria for a case study. Therefore, the research shifted to a narrative design. Ultimately, the narrative design allowed me to best describe the experience of a single participant's experiences in the MS program, as well as the story of the MS program itself. These experiences and details of teacher knowledge development were best told through a narrative framework, in combination with the constructivist approach.

As I became more involved with the MS program, I learned more about the teachers' educational backgrounds. The teachers come in with a STEM undergraduate degree. Additionally, these teachers have already earned a teaching certificate, so they come into the MS program with pedagogical knowledge from their teaching certification courses and prior teaching experience. Seventy-five percent of the courses in the MS program focus on chemistry concepts. Therefore, part of my work was observing the merger of these knowledge bases, resulting in PCK change.

Narrative Profiles

Through this narrative design, one teacher was followed through their experience in the MS program. In order to maintain confidentiality of this teacher's identity, I will use the pseudonym Taylor and use they/them pronouns when referring to the narrative participant. Taylor is a veteran teacher coming from an urban school in a Midwestern state. By conducting individual interviews and virtual teaching observations, monitoring content knowledge change, and periodic surveying of course and MS program experiences, I was able to gather data representative of the teacher's comprehensive experience to form a narrative.

An additional narrative crafted during this study involves the MS program as a whole. I was able to collect data across all teachers in the MS program so that I could talk about the overall participants in a narrative fashion. By compiling the experiences of current participants and alumni, the narrative of the MS program itself emerged on its own account. Data was collected from a subset of participants in Fall 2022 regarding their teaching experience. Of the eighteen respondents, seven had taught for 5 years or fewer, three had taught for 9-12 years, and the remaining eight teachers had taught for at least 15 years with the longest teaching career being 27 years. In terms of educational background, data from 38 respondents found that 55.3% had a chemistry or chemistry education background, while the remaining 44.7% came from another scientific discipline prior to the MS program. Just over half of participants (52.6%) had earned an additional graduate degree before enrolling in the MS program. Of fifteen alumni, two participated in the MS program during the period of the study and graduated in Summer 2022 and the remaining thirteen had participation ranging from Fall 2014 to Summer 2021.

Personal Bias

Qualitative researchers must “position” themselves in their reports by disclosing the biases, values, and experiences that they bring to their research.[7] My experiences and values that relate to the present study were discussed in the Researcher Background section above. The bias that I may introduce into this study includes my personal opinion of educators and my involvement in the study as a GTA.

Some bias stems from my personal view of educators. I have great admiration for teachers and view teaching as one of the most important vocations that exists. I did not have chemistry teachers that impacted me beyond my development of chemistry knowledge, but I have had teachers in other disciplines who positively influenced my life during my formative years.

I believe that effective teachers are highly skilled and knowledgeable. When conducting data collection and analysis, I found myself thinking: “Who am I to evaluate a teacher’s effectiveness when I myself am not a teacher?” I do not possess any form of teaching certification. Throughout this project, I have addressed this bias by attempting to maintain an objective view of the participants’ performance both as teachers and learners, relying on my expertise as a qualitative researcher. In essence, I was qualified to conduct this study, even though I am not myself a teacher.

Some potential sources of bias relate to my role as a GTA. By assessing teacher coursework, I was in a position to make judgments on individual teacher knowledge and ability. This could then impact my perception and interpretation of data collected in the study. For example, if I perceived that my narrative participant excelled in the MS program courses, it might skew my analysis of the participant's teaching observation. Additionally, poor performance on or completion of course assignments could influence my perceived reliability of their feedback on the course itself. The opposite would also be true: a participant's superior performance in courses could cause me to favor their feedback.

As the researcher, I took steps to ensure that I could eliminate as much bias as possible in this study. I was able to avoid bias in these situations by interacting with and observing participants in the MS program while isolating myself from my personal views on teachers and the teaching profession. I have received adequate training to work with people in research settings and utilize the resulting data in an impartial manner. In regard to my role as a GTA, I was able to grade assignments blindly without seeing the participants' names and all coursework that was used for research was assigned a code, so my data has been separated from any identifiers that could result in biased analysis.

Guiding Research Questions

In qualitative studies, guiding research questions focus data collection on specific areas of interest.[8] The following guiding research questions were developed in order to focus our goals and seek to answer how teachers experience PCK and professional development through the MS program requirements:

- How effectively do courses deepen participants' chemistry content knowledge?
- How do participants evaluate their own teaching? How do they implement changes in how they teach as a result of this MS program, if at all?
- How does this MS program impact participants' PCK?
    - How do participants learn more about teaching through this MS program?
    - How do participants become more effective educators?

After beginning data collection, our initial research questions were revised in order to target specific changes that may result from the MS program experience. The initial research questions were broad and there was overlap between questions. The revised questions above are distinct and can be answered individually using the chosen data collection methods. Additionally, the initial questions could not realistically be answered within the timeline of the project. An example question is as follows:

- How do participants analyze the effect of these changes in their teaching using research skills developed in this MS program? How do these changes impact student learning?

In order to answer this question, a great deal of intervention in the teachers' respective classrooms would be required, which is beyond the scope of the current study.

Dissertation Overview

In Chapter 2, I will describe the studies in the literature which provided a foundation for this study. In Chapter 3, I will detail the study design and methods that were developed to best answer the guiding research questions. Chapters 4 and 5 will share data collected for the narratives: one on the single narrative participant and one on the overall program participation. Chapter 6 will be dedicated to sharing participant feedback on courses and the program in general. To conclude, Chapter 7 will discuss themes that emerge from each data chapter to share the outcomes of the study. Conclusions will be drawn in regard to the MS program's success with providing courses and experiences that allow the teachers to develop into more effective educators.

CHAPTER 2: LITERATURE REVIEW

Introduction

The purpose of this project was to evaluate the MS program with respect to its impact on teachers' effectiveness. For this research, I used a social constructivist framework and narrative research design. Data collection and analysis involved mixed methods, including both qualitative and quantitative data through surveys, interviews, observations, and coursework. The chosen methods allowed me to collect data that could be used to describe changes in the teachers' content, pedagogical, and pedagogical content knowledge (PCK) who participated in the MS program. The methods, framework, and research design were derived from and supported by the literature.

Philosophical Assumptions

Philosophical assumptions are beliefs and perspectives held by the researcher that provide structure and direct the study's focus.[9] These philosophical assumptions impact the research questions that guide the study and inform how the researcher's beliefs and experiences impact their capacity and motivation for conducting the research. The four philosophical assumptions are ontological, axiological, epistemological, and methodological.

Ontology

Ontology discusses the nature of reality, existence, or truth.[9] From a constructivist perspective, our reality is created based on what we know, which is constructed by the individual based on prior experiences.[10-12] Truth and reality depend on what is known by the individual. One example of multiple realities is the classification of Pluto as a planet or dwarf planet.[13] As new information is identified and reviewed by the individual, new meaning can be constructed. Multiple realities can be viewed from the perspective of the individual or of a community, as illustrated by the changing consensus of Pluto's classification by astronomers. Although the consensus of the astronomy community shifts as a result of new knowledge, individual astronomers may interpret data or new findings contrary to this consensus. The nature of reality evolves over time. Each participant in the MS program has their own perspective on reality; thus, each participant is given equal weight in their representation of their own experiences and truths.

As discussed in the introduction chapter, my reality as a researcher is that I bring in my own prior experiences with research and education that inform my research decisions. It is important to represent multiple experiences and perspectives of the MS program participants, both through the narrative of a single participant and through a collection of statements gathered from the general population of the MS program. Social and individual interactions are important to monitor as they inform knowledge change and learning. Through this study, I navigated the changing realities of my participants as they gained knowledge and skills through the MS program.

Axiology

Axiology discusses the role of values in research.[9] I personally have values both in regard to the role of teachers in our society and the role of unbiased educational research. My personal values and bias are discussed in depth in the introduction chapter. My general beliefs are that teachers play an important role in guiding and supporting the growth of their students. I also believe that qualitative educational research provides detailed accounts of participants' experiences that cannot be understood by the research without taking into account each individual's values.

Because I am embedded in the study as the instrument, I am present in the research itself as part of the collection, interpretation of, and discussion of implications of the data. It is important that I isolate my work with participants and data from personal biases and treat the process ethically. During data collection, I attempted to establish good rapport with my narrative participant by allowing for flexibility, clear communication, and a supportive environment. I express deep gratitude for their participation in this study, while maintaining that they are able to end participation at any time. Through the process of data analysis and interpretation, I have done my best to preserve participants' intended meanings. Through my many interactions with the MS program participants, I have not shared my personal opinions to ensure that I do not bias their thoughts with my own perspectives and experiences. Validation and reliability methods, which will be discussed in greater depth in the methods chapter, allowed me to ensure that my representation of the data was true to my participants' experiences. Through member checking, I was able to confirm with my narrative participant, program participants, and instructors that my interpretation of their interactions with the courses and communications with me was accurate to their personal values.

Epistemology

Epistemology is the theory of knowledge that provides a foundation for the study.[9] The foundational philosophical theories that inform my epistemological beliefs will be discussed in the interpretive framework section. In essence, the theory of knowledge for this study places focus on the individual learner. Knowledge is adapted and created by each individual participant in the program. In the MS program, knowledge is constructed by the learner in a collaborative learning context. Participants are constructing knowledge: 1) through their own practice as they teach students in their own specific contexts; 2) through individual learning in the MS courses; and 3) through their engagement in the MS program by interacting with peers, professors, and teaching assistants through coursework and beyond. Knowledge that the researcher gains as a result of this study is constructed from the experiences of the participants.

Methodology

Methodology describes the research process itself.[9] This study utilizes a narrative design, although case studies were initially identified as a good fit. In qualitative studies, the methodology can be adapted and modified throughout the course of the project. These changes to the methods are shaped by the researcher's experience collecting and analyzing the data.[9] Over the course of this study, data collection or analysis methods were altered or added due to insufficient participant recruitment, participant feedback, or other factors which are detailed in the methods chapter.

Interpretive Framework

An interpretive framework is a model, theory, or belief informed by the researcher's philosophical assumptions – especially the epistemological – that is used to conduct research.[9] Constructivism is an approach that argues that knowledge is constructed by the individual as a result of experience and prior knowledge. For this study, it is necessary to expand our view of constructivism to involve the social context of the program. Thus, social constructivist theory guides the design and data collection for this project as its interpretive framework. The idea for this philosophical model is rooted in the philosophies and theories developed by past philosophers and psychologists.

Foundational Philosophies and Theories

In order to discuss constructivist theory, it is important to discuss theories and philosophies of knowledge. First came the thought focused on epistemology, or the theory of knowledge. Aristotle discussed that all knowledge stems from pre-existing knowledge.[11] He claimed that knowledge is not innate, but instead comes from a collection of memories or experiences.[11] Similarly, Locke asserted that knowledge comes from lived experience and is not innately possessed by all individuals.[14] These philosophies presented a theory of empirical knowledge, meaning that Aristotle and Locke believed that all knowledge comes from experiences and observations.[11, 14] Continuing in a similar vein, Kant posited that all knowledge begins with experience or reason.[12] Knowledge can be brought about by experience but also by impressions.[12] These impressions could be derived from ideas or opinions held by the individual that led to constructed knowledge despite the individual's lack of personal experience with a particular concept or skill. Departing from the views of Aristotle and Locke, Kant believed that knowledge can be constructed without personal experience or observation. Vico deviates further from the idea that knowledge came from experience, stating that all knowledge is created or made by the individual.[15] These philosophers' treatment of knowledge laid the foundation for future work related to epistemology, later translating to constructivist theory.

From theoretical conceptions of knowledge came pragmatism, which deals with practical applications of philosophy. Peirce, who is credited with originating pragmatic theory, believed that for a concept to be meaningful, it must also be practical.[16] Peirce mentored Dewey, who later conceptualized epistemology for the learning environment, stating that “education is…a reconstructing of experience.”[17] Although knowledge may be gained through experience, it must be reconstructed in the mind of the learner. Dewey criticized educators who continued to practice passive learning techniques, stating that education is an “active and constructive process.”[17] These ideas promoted learner-focused pedagogy in place of traditional instructional methods and brought constructivism into education.

Similarly, Piaget brought constructivism into an educational context through the lens of cognitive psychology. According to Piaget, as influenced by Kant, knowledge is an individual’s interpretation or internal transformation of reality.[18, 19] Knowledge is therefore constructed by each learner based on their current level of cognitive development. Piaget focuses on stages of a child’s cognitive development and relates that knowledge is relayed and constructed differently at each of these stages.[18] For Piaget, knowledge is not transmitted to the student by the instructor; instead, students construct or reconstruct their own knowledge.[20] Piaget’s cognitive constructivism later influenced future interpretations of constructivism, such as the radical theory supported by von Glasersfeld.[21] As a result of this influence, both Piaget and von Glasersfeld focus on how knowledge is constructed by individuals. In addition, von Glasersfeld invites in the notion that “others” – those who form the social context – are constructed in the mind of the learner, which distinguishes his philosophy from that of social constructivists.[22] Maintaining focus on the individual, Piaget’s cognitive constructivist theory can extend into adulthood. Individuals of all ages construct knowledge based on their current level of thinking. Conceptual change describes the phenomenon that occurs when learners must accept new knowledge and reconstruct existing knowledge of a concept.[23] This process will be discussed in more detail later in this chapter.

Ausubel was also inspired by Piaget's cognitive constructivism. Some of his contributions to educational psychology focused on meaningful learning. Meaningful learning is defined as learning that is potentially meaningful to a learner, depending on the learner's cognitive structure.[24] Ausubel's Assimilation Theory relates that "new meanings are acquired by the *interaction* of new, potentially meaningful…knowledge with previous learned concepts."[24] As with other views on constructivism and epistemology, meaningful learning involves interaction with an individual's prior knowledge. Ausubel criticizes certain constructivist views, noting that allowing students to independently construct knowledge paves the way for misconceptions and biases.[24] When utilizing constructivist techniques, it is important to evaluate students' prior knowledge and ascertain students' understanding of a new concept.

In contribution to previous work on constructivism, Vygotsky added that learning is a collaborative process.[25] That is, students take an active role in the learning process and this learning takes place in a social context. Vygotsky formulated a learning theory to demonstrate how students are able to construct new knowledge in a social learning environment. His conception of the Zone of Proximal Development (ZPD) illustrates the distance between a student's actual development and their potential development. The actual development level is characterized by individual problem solving, whereas potential development involves problem solving supported by guidance from peers or a teacher.[25] The ZPD theory demonstrates that guidance from an instructor or collaboration with peers impacts a student's potential development.[25]

Social Constructivism vs. Radical Constructivism

Radical constructivists believe that teaching and learning are processes that occur individually, apart from any social interactions that occur.[6, 26] Radical constructivism describes how individuals construct knowledge of the world from within their own minds.[26, 27] Constructivists believe that knowing is an adaptive activity, meaning that each individual constructs knowledge as a result of creating a personal collection of viable concepts and models that best suit the context in which the individual is situated.[6] There is no single truth or method for creating knowledge, as it is constructed by the individual and relates to one's own experiences and prior knowledge. Due to his belief that knowledge is constructed by the individual, von Glasersfeld supports the constructivist claim that there will always be more than one way of solving a problem or achieving a goal.[6]

As a radical constructivist, von Glasersfeld attempts to separate an individual's ontology from epistemology; that is, the subjectivity of an individual's reality exists independent from knowledge.[21, 28] Following Locke's beliefs on knowledge, von Glasersfeld relies on the subjective nature of knowledge construction.[29] In his view, knowledge is constructed by the individual dependent on one's own experience.

Social constructivists place value on the collaborative nature of learning. Dewey emphasizes the social nature of learning and meaning making, believing that all meaning is created through social interaction.[30] For Dewey, the epistemology and ontology are intertwined: knowledge is a part of the individual's reality.[31] As a community of learners gains knowledge, new perspectives, and insight, they do so through situated learning with each other.[32] In this MS program, participants often learn in community with one another, through discussion forums and Zoom discussions. Although knowledge is constructed by each individual participant based on prior knowledge and experience, much of this construction is done in a social context by way of peer collaboration. Under social constructivism, learners depend on each other to construct their own foundational knowledge.

Social Constructivism

Social constructivism best suits the goals for this project because teaching is an inherently social role. Each MS program participant is shaped by their personal experiences, past knowledge, and professional context, which inform how they construct knowledge gained throughout the MS program. The MS program participants are constantly constructing new knowledge and adapting existing knowledge as they gain new information, create new models, and situate these experiences in their own contexts. Takeaways from this MS program may manifest themselves in different ways for each teacher. Content and pedagogical knowledge are constructed by each participant and implemented in the classroom using strategies unique to each teacher. Using a social constructivist framework means relying on participants' perspectives on their experience.[9]

Participants interact with each other virtually during an MS course in a variety of ways including discussion forums, a sharing project, and Zoom discussions, and organized study groups with peers. Participants also interact face-to-face while they are on campus in the summer sessions. While on campus, participants give each other feedback on their research, share ideas during live discussions, and also learn from their instructors and the graduate students who assist them in the research lab.

Apart from the MS program, each teacher brings their own experiences and knowledge from their background and teaching context. Because the MS program is online, MS program participation is geographically diverse. There are teachers from a wide variety of states, each with their own content standards or learning expectations. Additionally, teachers come from different school district settings (e.g. rural, urban). These differences in contexts form different experiences and mindsets for what and how concepts must be taught in their specific classrooms.

In terms of background, all teachers have completed some form of teacher certification, requirements of which vary depending on the state in which they completed the certification. Some of the teachers have 4-year degrees in chemistry, while others focused their study in a different scientific discipline and are participating in the MS program in order to fill gaps in their chemistry knowledge. Furthermore, some participants have already completed a Master's in Education or doctoral degrees in their respective field prior to participating in the MS program. The educational background and teaching contexts contribute to the diversity of the MS program participants, as well as personal experiences pertaining to their gender, race, sexuality, and other aspects of their identities.

Approach to Inquiry

The approach to inquiry chosen for any particular study informs which data collection and analysis methods should be utilized to carry out the research. Creswell & Poth report five approaches to inquiry for qualitative research.[33] During the initial stages of preparation for this study, case study research seemed like the best option to describe individual participants' experiences in the MS program. As data collection progressed, we moved away from case studies and decided to pursue a narrative approach. There are similarities between the two approaches; however, narrative research emerged as the best fit for our study in order to provide answers to our guiding research questions.

Case Study Research

Case studies utilize mixed methods in order to describe and analyze a specific case, or subject, over an extended period of time using multiple data sources.[33] In the case of this research, we intended to follow multiple cases – teachers who were new to the MS program – through their full experience in the MS program. The timeframe and participation criteria were well-defined, which is important to the case study approach.[33] In order to achieve our research goals, we needed to obtain an in-depth account of the participants' experiences in the MS program and this aligns well with the parameters of a case study. We had hoped to recruit at least five incoming teachers in the fall semester of 2021; however, I was only able to successfully recruit a single participant. At that point in time, we made the decision to move toward the narrative approach.

Narrative Research

The qualitative approach to inquiry used in this study is a narrative research approach. The purpose of a narrative study is to tell stories of individual experiences.[33] Narrative studies focus on a small number of participants, which suited the recruitment for this study where two narrative accounts have emerged – a single teacher and the MS program itself. Using the narrative approach, I was able to describe the phenomena that surround participants' experiences in the MS program and how it has impacted their own teaching practice. The function of narrative research involving teachers focuses on understanding teachers' beliefs and practices through explanations of their experiences without elucidating the cause of their behavior.[34] That is, narrative research does not aim to determine why behaviors occur, but instead focuses on describing the purpose of such behaviors. By using a narrative study design, the researcher can use personal accounts from the narrative participants to explain the participants' reality.

Narrative stories emerge from methods including interviews, surveys, journals, and coursework. The participants share their experiences, which are retold by the researcher. One data analysis procedure specific to narrative research is restorying. Restorying involves reorganizing stories that emerge from data collection to fit a chronological timeline or to best analyze the data into its resulting themes.[33] In this way, the researcher is able to communicate an account of the participants' stories with a logical flow that is true to the participants' lived experience. Restorying also allowed for the participants' experiences to be detailed in the sequence in which the MS program was conducted.

Remote Data Collection Methods

The present study involves a population of remote graduate students. Because of the virtual nature of the MS program, all data has been collected utilizing remote data collection methods. Trate et al. discuss the positive aspects of performing remote data collection, such as the ability to collect data from a geographically diverse sample and lower time and money costs.[35] This has certainly been true for this project, as participants come from across the United States and abroad. The existence of online multimedia platforms, such as Zoom, QuestionPro, Google Forms, and Desire2Learn (D2L), allows for remote face-to-face interviews, survey platforms, and homework collection depositories.[35] Individual interviews with my narrative participant have been conducted virtually via Zoom. Surveys for the entire group have been conducted via QuestionPro, Google Forms, and D2L. Trate et al. confirmed the validity of remote data collection and analysis and demonstrated that there is consistency between in-person and remote data collection.[35] As this project's data have been collected remotely, studies like these are important to establish evidence that remote interview methods uphold the integrity observed in face-to-face data collection and analysis.

Weller discusses implications for rapport in virtual, face-to-face interviews. Rapport is the process of building foundational respect in the researcher-participant relationship, as well as gaining the confidence of the participant.[36, 37] Disruptions to the internet connection challenge rapport and data quality and the interviewer must ensure whether or not the conversation in question was impacted by any interruptions.[37] Weller concedes to prior research findings that point to focusing on interpersonal interactions in order to maintain the long-term research relationship.[37] Conversely, remote interviews provided a less formal and more flexible environment for the participant, thus reducing the anxiety or pressure that exists for in-person interviews.[37] Virtual interviews are as effective as physically present encounters.[35, 37, 38] This upholds the validity of remote data collection methods for interviewing, which was a primary and essential method for this narrative study.

Although remote data collection methods were necessary due to the geographic diversity of the study's participants, remote methods also functioned to place the researcher in a similar context to the students. This allowed me to better understand participants' experiences as students in an online MS program, as I was experiencing the course delivery format and video conferencing software in the same way as the participants.

Resulting Research Framework for the Current Study

The interpretive framework best suited to the purpose of this study is social constructivism. Teachers participate in the MS program remotely, but engage with their peers through coursework and, as evidenced through participant responses, apart from the MS program's requirements as well. Thus, teachers learned in a social context. A narrative study design was implemented to learn in depth about teachers' experiences in the MS program. Remote data collection methods were utilized due to the virtual nature of the MS program. The methods discussed in the following chapter were selected and adapted to fit the research framework for the study in order to focus the research on answering our guiding research questions. Because most evaluations of academic programs are done internally, there is a gap in the literature for formal evaluations of programs similar to the MS program in focus for this study. There are, however, studies focused on teacher education, in the form of distance education programs, continuing education, and professional development interventions.

Conceptual Change

Due to the nature of science, scientific knowledge is constantly evolving. Relating to Piaget's cognitive constructivist theory, when teachers are exposed to a new idea, they must accept new knowledge and change their mental process by reconstructing their knowledge of a concept.[23] This process is described by Strike & Posner's notion of conceptual change.

Kuhn described how scientific progress requires continual research and investigation, meaning that theories and concepts always undergo change.[39] Thus, science teachers must adapt their current knowledge as conceptual changes arise. In opposition to Kuhn's revolutionary perspective, Toulmin offers an evolutionary perspective inspired by Darwin's biological model.[40] Instead of exchanging knowledge as new ideas arise, Toulmin describes how learners ought to embrace new concepts through innovation while debating the fitness of replacing a concept through selection.[40] Thus, Toulmin's perspective encourages learners to engage with new ideas before accepting them and adapting prior knowledge to fit novel concepts.

Strike & Posner offer conditions that must be fulfilled in order for conceptual change to occur: 1) the existing concept must be unsatisfactory; 2) the new concept must be "intelligible"; 3) the new concept must be "initially plausible"; and 4) the new concept must "open up to new areas of inquiry."[23] Essentially, in order for learners to accept conceptual change, the new concept must be understandable, create a possibility for further inquiry, and replace a concept that is lacking in efficacy. Learners can experience conceptual change when new, logical information is introduced that supersedes existing models or ideas.

Throughout the MS program, new concepts – or the greater depth of a concept – are provided within the coursework, meaning teachers experience conceptual change. In this study, multiple methods are used to better understand how teachers involved in the MS program react to conceptual change and how they implement these changes in their practice.

Pedagogical Content Knowledge (PCK)

In the 1980s, Lee S. Shulman developed the concept of pedagogical content knowledge (PCK) as a professional knowledge base exclusively for educators.[1] He writes that PCK "represents the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction."[1] PCK is of great importance to this study, as it will be used to measure teacher transformation as a result of participation in the MS program.

Components of PCK

Lee and Luft investigated PCK from the perspective of the teacher, stating that much of the research on PCK comes from the perspective of the researcher.[41] Case studies were used to understand what secondary science teachers identify as the components of PCK and how these elements are organized in order to conceptualize PCK.[41] Their study found that experienced science teachers – defined as having more than ten years of teaching experience – conceptualize PCK using knowledge associated with the following terms: science, goals, students, curriculum organization, assessment, teaching, and resources.[41] The authors noted a gap in PCK research with teachers' desire for knowledge of science teaching resources and whether resources are a true component of PCK.[41] Van Driel et al. compare knowledge components as identified by various PCK researchers and common categories included: subject matter, representations and strategies, student learning and conceptions, general pedagogy, curriculum and media, context, and purposes.[42] Each of these knowledge components was not included by every

PCK expert; however, these components parallel those which were presented by Lee and Luft, which supports the use of these components for the current study.

Research on Teacher Development of PCK

PCK develops over time and is dynamic.[43] In this project, PCK was captured both at a single moment in time and measured across the spread of two years in the MS program. One of the goals of this study was to understand how teachers' PCK develops over the course of the MS program. Individuals construct knowledge over time, so it is important to track these knowledge changes through participants' entire program experience.[44] Abell encourages researchers to investigate the quality of PCK, not only its existence or quantity.[43] The data analysis for this project attempted to assess the quality of PCK in addition to its presence.

In a study focused on teacher PCK development, Coenders & Verhoef found that it was more challenging for experienced teachers to change their practice than it was for beginning teachers.[45] The MS program in focus involved teachers at all stages in their careers. Through this evaluation of the MS program, we wanted to understand whether or not teachers change their practice as a result of what knowledge they constructed during the MS program. Therefore, we investigated whether the level of experience of the teacher impacted their willingness to change their teaching practice.

Modules

In order to collect data from MS program participants through coursework, as well as to monitor changes in teachers' PCK across semesters, two modules were created and implemented in the MS program's six content courses. One of the modules was adapted from a tool in the literature called a Content Representation, or CoRe. The second module – the Teaching Script – was inspired by a study in the literature, but greatly diverged from the original work. In order for the modules to be meaningful, they were situated in contexts described by Loughran et al. The CoRe focused on the teacher's thinking about content and student responses, whereas the Teaching Script placed the teacher in the classroom reality, or the complexity of a real teaching situation.[46]

Content Representation (CoRe)

A content representation (CoRe) is a method developed by Loughran, Mulhall, and Berry in order to document and portray science teachers' PCK.[46] A CoRe is noted as a tool to "access science teachers' understanding of the content as well as a way of representing this knowledge."[46] Participants are asked to detail their understanding of a scientific concept, share how they intend to teach this concept, and determine factors that influence their teaching.[46] The CoRe allows researchers to capture science teachers' PCK in ways that can be useful to other science educators.[46] The CoRe method was used in our research to develop a module to measure participant PCK. Our module used the questions as outlined in the methods section in order to replicate the use of the CoRe in this study.

Hume and Berry found evidence that creating CoRes aided in the development of PCK because constructing a CoRe requires the teacher to articulate their own professional knowledge.[47] Designing CoRes helped the teachers to better understand the content as well as how they intend to teach these topics.[47] One purpose of the CoRe module was to give the teachers in the MS program the opportunity to apply their content knowledge to their classroom context. The CoRe module also allowed teachers to practice communicating their content knowledge in concert with their pedagogical knowledge, thus potentially further developing their PCK.

Teaching Script

Stender et al. investigated the relationship between topic-specific professional knowledge (TSPK) and teaching scripts, both of which comprise PCK.[48] Forty-nine in-service physics teachers shared their teaching scripts, beliefs, motivation, and self-regulation through development of a lesson plan, which was analyzed to retrieve the teachers' teaching script for the given topic.[48] This study informed the development of our module on teaching scripts, through which our participants demonstrated any changes in their PCK. This study's treatment of teaching scripts was used as a starting point as we created the Teaching Script module.

Teacher Professional Development

In 1994, teacher professional development was brought to the forefront with the passing of new National Education Goals by the United States Congress. One of these goals was to improve teacher professional knowledge by the year 2000.[49] This particular goal focused on access to pre-service teacher education as well as continual professional development for in-service teachers.[49]

Professional development focuses on teacher learning but in turn can impact student learning.[50] Taitelbaum et al. investigated the professional development of chemistry teachers participating in a continuous professional development (CPD) program.[51] The CPD program focused on inquiry in the laboratory and this study observed participants' use of inquiry-based experiments in their own classrooms.[51] Changes in PCK and chemistry content knowledge were observed throughout the teachers' involvement in the CPD program and observations sought to measure how teachers coped with implementing ideas learned in the CPD program.[51] Individual interviews took place after teaching observations in order to understand the teachers' implementation of an inquiry-based experiment and the teachers' thoughts surrounding these activities.[51] The utilization of inquiry-based learning transitioned the classroom learning from teaching-centered to student-centered activities.[51] Evidence was provided that teachers changed their practice as a result of the CPD program and helped to further develop their content knowledge and PCK.[51] In addition to practicing PCK through the module assignments, teachers in the MS program come to the SDSU campus in the summers to conduct laboratory research alongside graduate student mentors. During this time, they develop laboratory activities to bring back to their classrooms. These summer sessions give the MS participants a unique opportunity to gain content knowledge and PCK, while practicing new laboratory skills. Taitelbaum et al. demonstrated that professional development, particularly related to lab development, can impact teachers' PCK and content knowledge. Our present study aimed to understand how teachers are impacted by their experiences in the MS program and how it informed their teaching practice. Surveys and interviews were used to learn more about MS participants' experiences in research labs on the SDSU campus and to understand how laboratory development impacted MS participants' PCK.

Similar to the summer sessions at SDSU, White & Goldberg describe a summer research program for high school science teachers.[52] This summer research institute was implemented so that in-service teachers could become more aware of current scientific issues and bring new knowledge of career opportunities in science into their classrooms.[52] White & Goldberg found that participants in the summer program gained an enthusiasm for scientific research that they could incorporate into their instruction.[52]

The teachers also developed relationships with each other and spent time together outside of formal program requirements.[52] The present study has implications for teacher attitudes toward research, as well as the impact of interactions and relationships that were developed during program participation.

O' Dwyer presented a study involving a professional development program for high school chemistry teachers.[53] The author argued that professional development should be an active learning experience for teachers in order to inform their own practice.[53] The program allowed teachers to interact and share experiences, as well as to create course materials or develop new teaching practices.[53] The program also had a positive influence on the teachers' autonomy.[53] Positive experiences for teachers led to enhanced learning for students.[53] The goals and outcomes of O' Dwyer's research mirror the goals and findings of this study. The MS program contains professional development elements through its enhancement of chemistry content knowledge and scientific pedagogical knowledge. Throughout the MS program, teachers are given opportunities to create curricular materials for use in their own classrooms. Our particular research did not extend to changes in student learning, but O' Dwyer's outcomes showed that improved teacher professional development may improve student learning.

Under Vygotsky's Zone of Proximal Development concept, teachers can further develop through professional development by setting new goals over the course of their careers.[54] By improving their own learning, collaborating with peers, and reflecting on their pedagogical beliefs, teachers can enhance their professional teaching knowledge.[54] The MS program helped teachers make progress toward their own personal and professional learning goals.

Distance Education

Distance education is formal education which does not occur in the traditional face-to-face learning envirionment.[55] Distance education programs provide students with prepared curricular materials, use media for two-way communication with students, and often focus on the learning of the individual instead of a collective class.[55] Having evolved from correspondence education, distance education uses new media in order to communicate with students using modern technology.[56] Although distance education dates back to the eighteenth century, modern distance education involves remote students participating in courses and programs using computers.[57]

An important topic of research in distance education is to better understand how distance education compares to traditional course delivery. Balkin et al. investigated classroom management practices in a distance education graduate course.[58] Experiences of on-site versus remote site students were compared in terms of the use of technology, teacher-student interaction, student-student interaction, and classroom routines.[58] Although course performance was not affected in the distance learning format, instructor-student and student-student interactions were lacking compared to traditional learning.[58] Student-student interactions can be encouraged through online video conferencing, such as Zoom.[56] Because the current study surrounds a remote program, it was imperative to understand how the distance learning format impacts its participants, particularly interpersonal interactions.

In evaluating an asynchronous Master's program, Hislop focused on the following components in order to compare the asynchronous program to traditional instruction: quality of education, cost of education, and quality of experience.[59] The study revealed that convenience and collaborative learning were strengths of the asynchronous program, while face-to-face contact and effort were diminished compared to traditional delivery.[59] In the current study, participants are asked to evaluate the value for money of the courses compared to the benefit, as well as their opinions on the course delivery as a primarily asynchronous MS program.

Similar to the goals and context of the MS program, Robinson discusses an 8-week asynchronous online course for AP Chemistry teachers in Indiana.[60] The coursework relates to AP Chemistry topics, like the MS program, but focused further on the AP curriculum by dissecting the AP Chemistry exam.[60] By learning about the structure and expectations of the AP exam, teachers were better able to prepare their students, thus increasing their PCK.[60] Although the MS program does not explicitly utilize past AP exam questions, the content of the MS courses supports PCK change by deepening teachers' chemistry content knowledge in conjunction with assignments through which teachers can model changes in their own teaching. Although the course was online and asynchronous, Robinson also notes that the course allowed teachers from across states to form professional relationships with one another.[60] Data from this study also supports the community-building potential of this online MS program for geographically diverse science educators.

With the COVID-19 pandemic, distance education became more prevalent due to social distancing and quarantine practices.[61] Although this MS program has been in place since 2008, virtual course delivery has become more common since 2020. Therefore, the outcomes of this research in terms of distance education may be more relevant because of increased student-teacher interactions in virtual formats.

Conclusion

The literature provided support for the framework and methodology used in this study. Prior work has laid the foundation for the use of social constructivism in qualitative educational research and best suited our evaluation of an online MS program for teachers. A narrative study also suited our needs to gain a better understanding of what teachers experience throughout their time in the MS program. The narrative design allowed for the collection of detailed testimonies of teacher transformations as a result of the MS program's requirements.

As mentioned above, it is uncommon to publish evaluations of graduate education programs. This study has provided information regarding how teachers respond to a chemistry content program involving teacher professional development. Through this work, we were able to identify which aspects of the MS program helped its participants become more effective educators, which aspects may require change, and how teachers' experience in the MS program impacted their work in their own classrooms. The philosophical assumptions, interpretive framework, theory, and prior studies in the literature all combined to support the data collection and analysis methods we used to answer our guiding research questions.

CHAPTER 3: METHODS

Study Design

This study followed a social constructivist framework and utilized a narrative study design. Initially, I planned for a case study design in order to follow multiple teachers from the Fall 2021 incoming cohort through their entire experience in the MS program. Two teachers were successfully recruited; however, one of the participants no longer fit the recruitment criteria after the first semester. At that point, the study shifted to a narrative design, following the remaining participant through their two years in the MS program and using data collected from all students in the program to create a narrative of the program.

The aims of this narrative study were twofold: 1) to follow a single teacher through their experience as a participant in the MS program; and 2) to study the MS program itself over the course of two years. The MS program, as a narrative of its own, was studied by collecting data from its participants through coursework, journals, and surveys. From the constructivist perspective, the teachers entered into the MS program with existing knowledge and actively construct new knowledge individually through their interactions with the content and other participants. Under the narrative design, data are collected about the teachers' experiences in the MS program in order to elucidate the impact of the MS program on the transformation of teachers' PCK.

IRB and Ethics

An IRB proposal was submitted and accepted in the summer of 2021. To reflect the change in study design, a requested change was submitted and accepted in early 2022. Both IRB approval letters can be found in Appendix A. The narrative participant was recruited on a volunteer basis and gave consent to all interviews, observations, and surveys. The narrative participant also completed a site permission form so that Zoom teaching observations in the teacher's classroom could be used for research purposes (Appendix B). Other participants gave consent via the survey platform before submitting surveys used for research purposes.

Study Population

Through this narrative design, I followed one teacher, who will be called Taylor, through their experience in the MS program. Taylor is a veteran teacher coming from an urban school in a Midwestern state. Taylor began the MS program in Fall 2021 and graduated in Summer 2023. By conducting individual interviews and virtual teaching observations, monitoring content knowledge change, and using periodic surveys of course and MS program experiences, I was able to gather data representative of the teacher's comprehensive experience to form a narrative.

An additional narrative crafted during this study involves the MS program as a whole. I was able to collect data across all teachers in the MS program so that I could talk about the overall participants in a narrative fashion. Participants in the MS program from Fall 2021 to the Summer 2023 contributed to the data collected for this project ($N = 47$). In the late summer of 2022, alumni of the MS program were also invited to complete a survey about their overall experience in the MS program ($N = 17$). By compiling the experiences of current participants and alumni, the narrative of the MS program itself emerged as its own account.

MS Program Courses & Timeline

The MS program content courses follow a two-year sequence. The timeline of the courses during data collection for this project, as well as the course titles and descriptions, are provided in Table 1. Each semester will be abbreviated as described in Table 1 throughout the remainder of this chapter and all subsequent chapters.

Table 1. Timeline of Courses Involved in Data Collection

Semester	**Course(s)**	**Instructor**
Fall 2021 (F21)	CHEM 770: Atomic Theory & Bonding • This course will examine topics in atomic theory including wave-particle duality, wavefunctions, atomic spectra, quantum numbers, and the relationship between electronic structure and the periodic table. These topics will provide a foundation to explain molecular bonding, which is the final section of the course. Topics of molecular bonding will include ionic and covalent bonding, electronegativity, polarizability, valence-bond theory, and molecular orbitals. Student participation in discussions will lead to enhanced content and pedagogical content knowledge for the secondary science teacher.	Instructor A

	CHEM 771: Intermolecular Interactions & Phases of Matter • This course will examine the impact on a variety of physical properties made by attractive forces between molecules, atoms, and ions. Topics will include examining the existence and predicting the strengths of intermolecular interactions; predicting physical properties, such as viscosity, boiling points, and melting points based on the presence of intermolecular forces; and impact of intermolecular interactions on phases of matter. Student participation in discussions will lead to enhance pedagogical skills for the secondary science teacher.	Instructor B
Spring 2022 (Sp22)	CHEM 772: Thermodynamics • This course will focus on the relationship between energy, entropy, and the progress of chemical reactions, calorimetry, reaction enthalpy, standard enthalpy, entropy, and free energy. An emphasis will be made on the mathematical techniques used to calculate these relationships and on how these concepts explain chemical behavior. Student participation	Instructor C

	will lead to enhanced pedagogical skills and development for the secondary science teacher. CHEM 778: Chemistry Teaching Strategies • This course will focus on pedagogical and curricular strategies and the educational research that supports using these methods. The incorporation of pedagogical methods into science classrooms as modifications for or enhancement of traditional instruction will be the goal for participants. Additionally, the development of integrated curriculum that uses multiple content areas will be discussed. Pedagogical and curricular strategies developed during the course will be peer-evaluated and tested in individual classrooms.	 Instructor A
Summer 2022 (Su22)	CHEM 776: Laboratory Development • This course will focus on the development of laboratory strategies and activities for the secondary chemistry classroom. Students will receive guided instruction in laboratory techniques from content experts. From these experiences the participant is expected to develop several new laboratory exercises which will be shared among participants.	Instructor A

Fall 2022 (F22)	CHEM 774: Kinetics, Nuclear, & Electrochemistry • This course will focus on three important topics in chemistry: electrochemistry, kinetics and nuclear. The initial topics will focus on oxidation/reduction reactions as students manipulate redox reactions by balancing chemical reactions, predicting spontaneity of redox reactions, and explaining the function of voltaic cells. The second set of topics will include mathematical methods to study the speed of chemical reactions including average and instantaneous rates of reaction, rate laws, the law of initial methods, and integrated rate laws. The final topics will include changes within the nucleus of an atom resulting in the alteration of that atom will occur by identifying fundamental processes of nuclear chemistry. Biological effects related to nuclear reactions will also be discussed both qualitatively and quantitatively. Student participation in discussions will lead to enhanced pedagogical skills for the secondary science teacher. CHEM 775: Organic & Biochemistry • CHEM 775 is a course designed to provide	Instructor A Instructor C

	elementary applications of organic and biological chemistry concepts that are relevant to achieving excellence in secondary chemistry teaching. This course is intended for in-service science teachers who desire continuing education credits, or for those teachers who wish to acquire more depth in the content to improve their teaching.	
Spring 2023 (Sp23)	CHEM 773: Equilibria & Acid-Base Chemistry • This course will examine the reversibility of chemical reactions. The concept of dynamic equilibrium will be studied, and the law of mass action used to quantify the condition of equilibrium. Students will be able to predict the extent and direction of a chemical reaction and quantify species at equilibrium. Le Chatelier's principle will used to study the impact different factors on the equilibrium status of a chemical reaction. Topics in acid/base chemistry will be used to further explain equilibrium processes. Additionally, Bronsted-Lowry and Lewis theories, molecular structure relationships to acid/base behavior, weak acid/ base behavior, the	Instructor A

	acidic/basic behavior of salts, titration, and buffer solutions will be discussed. Finally, physical equilibria will also be reviewed regarding phase changes and solutions. Student participation in discussions will lead to enhanced pedagogical skills for the secondary science teacher.	
Summer 2023 (Su23)	CHEM 776: Laboratory Development • This course will focus on the development of laboratory strategies and activities for the secondary chemistry classroom. Students will receive guided instruction in laboratory techniques from content experts. From these experiences the participant is expected to develop several new laboratory exercises which will be shared among participants.	Instructor A

In addition to the courses listed in Table 1, teachers also participated in courses related to their action research projects. Data was not collected in these courses; however, CHEM 777: Action Research in the Secondary Classroom and CHEM 788: Master's Research Problems/Projects were referenced by participants in surveys and interviews. During the summer sessions, two elective courses were offered on campus. Participants were invited to enroll in CHEM 691: Waste Procedures and CHEM 691: Chemical Demonstrations in addition to CHEM 776 and relevant action research courses.

Three instructors were involved with the instruction of each of the MS program courses. Their codes are listed in Table 1 and will be used to reference each instructor when necessary in the data.

Research Methods

Data collection and analysis involved mixed methods, including both qualitative and quantitative data collected through surveys, interviews, observations, and coursework. Although mixed methods are used, this project is heavily qualitative. As discussed in the literature review, remote data collection methods were utilized due to the geographic diversity of the MS program participants and the online nature of the MS program itself.

Procedure

The narrative participant, Taylor, was recruited in early Fall 2021. The data collection timeline for the narrative is listed in Table 2. In Tables 2 and 3, a column of ID codes is listed which will be used to reference and organize data throughout the remainder of the dissertation.

Table 2. Narrative Data Collection Methods

Term	**Data Collection Methods**	**ID Codes**
Before Start of Program	Pre-content exam Initial survey	CE IS
Fall/Spring Semesters	**Beginning:** Initial interview (only in F21) Check-in interview (all but F21) Teaching observation (baseline) (only in	 II I TO

	F21) Pre/post observation survey (only in F21)	OS
	Late: Check-in interview (all but F21) Teaching observation Pre/post observation survey	 I TO OS
Summer Sessions	**Before campus:** Check-in interview	 I
After End of Program	Post-content exam Exit survey Exit interview	CE ES EI

Each semester followed a similar sequence. The first semester contained a few additional items, including the initial survey and initial interview, so that Taylor and I could get acquainted. These initial methods also served to provide a baseline for Taylor's goals and motivations for selecting this MS program, as well as other details of their background. To establish a baseline of Taylor's chemistry content knowledge prior to the start of the MS program, I proctored a content exam via Zoom. The post-content exam was completed after their completion of the program. Each semester, we had two check-in interviews via Zoom to discuss Taylor's experience in the MS program. An additional check-in interview was conducted during each summer session. Each Fall and Spring, I conducted a Zoom observation of Taylor's teaching in their own classroom. For their first semester in the MS program, an additional observation occurred in the beginning of the semester in order to establish a baseline of Taylor's teaching. At the conclusion of the study (once Taylor completed the MS program), I conducted an exit interview to discuss Taylor's final thoughts about their experience in the MS program and how it had impacted them moving forward. This interview included follow-up questions to their responses to the exit survey, which prompted reflection on their overall experience in the MS program.

Additional methods were used in order to collect data from the general population of MS program participants from Fall 2021 to Summer 2023. These methods also included the narrative participant. The timeline of this data collection is found in Table 3.

Table 3. MS Program Participants Data Collection Methods

Term	**Data Collection Methods**	**ID Codes**
Fall/Spring Semesters	**Beginning:**	
	Chemistry content survey (pre) (F22 only)	CCS
	Mid-semester:	
	Module(s)	
	- Content Representation	CoRe
	- Teaching Script	TS
	Module Surveys	MS
	Discussion Forums	DF
	Late:	
	End-of-semester survey	EOS
	Chemistry content survey (post) (Sp23 only)	CCS

	Midway Course Reflection	MCR
Summer Sessions	**Before campus:** ASCI (pre) Summer Journal #1	 ASCI SJ
	On campus: Summer Journal #2	 SJ
	After campus: Summer Journal #3 ASCI (post) Post-campus summer survey End-of-summer survey	 SJ ASCI PCSS EOS

In each of the content courses, module assignments were integrated into the course requirements in order to measure PCK change with a focus on course-specific content knowledge. After completing each module, participants were asked to complete a survey about their experience with the module and how it informed their engagement with a chosen topic. For content courses in the 2022-2023 academic year, participants were invited to complete a brief chemistry content survey focused on topics related to CHEM 774 (F22), CHEM 775 (F22), and CHEM 773 (Sp23). A pre-survey was administered in early Fall 2022 and a post-survey was administered in late Spring 2023. Certain discussion forums from courses taught by Instructor A were involved in data collection. At the end of each semester, an end-of-semester survey was sent out to all participants in the MS program courses in order to gain feedback on the participants' experiences in the courses and program overall. A Midway Course Reflection survey was given during the pedagogical course, CHEM 778 (Sp22), in order to learn about teachers' changes in PCK and any professional changes that resulted from taking this course.

Over each summer session, three journal entries were completed by participants to learn about participants' goals and experiences on the SDSU campus. A post-campus survey was given after the summer session, which prompted participants to reflect on their overall summer campus experience. A pre/post Attitude toward Subject of Chemistry Inventory (ASCI) was given to learn about the MS participants' attitudes toward chemistry laboratory research prior to and after their experience in a research laboratory on the SDSU campus. As with the Fall and Spring semesters, an end-of-summer survey was sent out at the end of each summer session in order to learn about participants' experiences in the on-campus summer courses.

Data Collection

As detailed above, various data collection methods were utilized over the course of this project in order to learn more about participants' experiences in the MS program. The details of each data collection method will be discussed below.

<u>Narrative Participant</u>

Initial Survey

An initial survey collected information regarding the participant's science and teaching background, as well as the teacher's goals for their experience in the MS program. The survey was administered through QuestionPro. The full survey can be found in Appendix C.

Initial Interview

Once the initial survey was completed, the participant was invited to schedule the initial interview. The initial interview was conducted virtually via Zoom. The interview followed up on the participant's Initial Survey responses and discussed motivations for choosing this specific MS program. Guided interview questions can be found in Appendix D. Through this interview, the teacher's teaching philosophy and goals for the MS program were also discussed.

Chemistry Content Exam (Pre/Post)

A chemistry content exam was created using free-response questions from past AP Chemistry exams (Appendix E).[2] The content of each question related to a specific course (or courses) in the MS program. The pre- and post-exams were proctored via Zoom and the teacher was asked not to reference any materials while the exam was in progress. After each of the problems on the exam were completed, the teacher was asked to answer the following two questions on a Likert scale from 1 to 6:

- How comfortable do you feel with the topics presented in this problem?
- How confident do you feel with the accuracy of your answer?

The teacher was given two hours to complete the content exam.

The pre-exam established a baseline for the participant's chemistry content knowledge. The post-exam was administered at the end of Taylor's experience in the MS program to gauge any changes in their chemistry content knowledge as a result of the MS content courses. The completed exams were graded using the official Scoring Guidelines provided by College Board for the AP free-response questions.[2]

Check-in Interviews

At the beginning and end of each Fall and Spring semester, Taylor was invited to participate in check-in interviews via Zoom. These interviews lasted 20-40 minutes, during which we discussed their experiences in previous and current courses and how any knowledge change was impacting their professional knowledge. These check-in interviews also served to help maintain rapport with my participant. Guiding questions for check-in interviews can be found in Appendix F.

Teaching Observations

Five times throughout the MS program, the narrative participant recorded themselves teaching a chemistry lesson. At the beginning of their first semester in the MS program, a baseline observation occurred in order to establish a baseline of Taylor's teaching in their own classroom. Each subsequent semester, I conducted a Zoom observation of Taylor's teaching near the end of each term. The observations were guided by the Danielson Framework for Teaching Evaluation Instrument (2013).[62]

Observation Surveys (Pre/Post)

Taylor completed a brief survey prior to and after recording an observed lesson, which described which lesson was taught, any anticipated student reactions, the teacher's confidence in teaching the lesson, and reflections on how the lesson went after the conclusion of the observation. The pre- and post-observation surveys were adapted from Park et al. in order to learn more about teachers' thought process during lesson development.[63] The pre- and post-observation surveys can be found in Appendix G.

Exit Survey

Upon completion of the MS program, Taylor was invited to complete an exit survey, following up on responses to their initial survey as well as discussing overall perceptions of their experience in the MS program. The exit survey can be found in Appendix H.

Exit Interview

The exit interview followed up on responses to the exit survey and allowed Taylor to reflect on their overall experience in the program. The guiding questions for the exit interview can be found in Appendix I.

<u>All MS Program Participants</u>

The following data collection methods involved participation from all teachers enrolled in MS program courses. Some of these data collection methods were formally integrated into graded coursework, whereas other methods were administered apart from the courses.

Coursework

Discussion Forums

Discussion forums were an integral component of most of the courses in the MS program, particularly for the content courses taught by Instructor A. In these courses, teachers were asked to discuss chemistry concepts and how this content related to their own teaching. The discussion forums offered a social context through which teachers could interact, share ideas, and request more information about what is being done in their peers' classrooms. Certain questions were introduced into two content courses, CHEM 770 (F21) and CHEM 773 (Sp23), in order to learn more about how teachers were changing their own teaching as a result of instruction from the MS program. The discussion forum questions related to the impact of the course on the teaching of specific chemistry topics, what changes participants carried out (or planned to carry out) in their classrooms, and what new knowledge the teachers took away from the discussion forums in general. Specific questions can be found in Appendix J.

Midway Course Reflection (CHEM 778)

In CHEM 778 (Sp22), a survey was administered midway through the semester to learn more about how this pedagogical course and other requirements of the MS program had impacted participants' professional knowledge and chemistry teaching strategies. This survey can be found in Appendix K.

Modules

Two modules [Content Representation (CoRe) and Teaching Scripts] were integrated into the MS program's content courses to measure changes in participants' PCK. The modules were adapted from the literature, as described in the literature review chapter.

- *Content Representation (CoRe)*

The CoRe module was used in CHEM 771 (F21), CHEM 772 (Sp22), CHEM 773 (Sp23), and CHEM 775 (F22). For each course, the CoRe contained a discussion forum component and required the completion of a table containing prompting questions from Loughran et al.[46] The CoRe assignment can be found in Appendix L.

- *Teaching Script*

The Teaching Script module was used in CHEM 770 (F21), CHEM 772 (Sp22), and CHEM 774 (F22). For each course, the Teaching Script contained both a discussion forum component and table of prompting questions like the CoRe but added a written transcript of a lesson and an organizational method, such as a PowerPoint presentation.[46] The Teaching Script assignment can be found in Appendix M.

Module Surveys

A survey was included in the module assignments in order to obtain feedback about the participants' experience completing each module. The module survey can be found in Appendix N.

Summer Journals

During the summer research experiences on the SDSU campus, all MS participants were asked to journal about their goals, professional growth, and general experience participating in laboratory research. Three journals included prompting questions and were submitted via Google Forms. Each journal entry extended over the teachers' time on the SDSU campus. The first journal was submitted prior to their campus experience, the second journal was submitted after their first week in a research laboratory, and the final journal entry allowed the teachers to reflect on their overall experience on campus. The prompting questions for each journal entry can be found in Appendix O.

Chemistry Content Survey (Pre/Post)

In order to gain a better understanding of how participants' chemistry content knowledge changes over time, a chemistry content survey was administered over the 2022-2023 academic year. This survey was created in order to supplement the data gathered from the single narrative participant's completion of the pre/post content survey, which included questions related to all content courses. For content courses in the 2022-2023 academic year, participants were invited to complete a brief chemistry content survey focused on topics related to CHEM 774 (F22), CHEM 775 (F22), and CHEM 773 (Sp23). A pre-survey was administered in early Fall 2022 and a post-survey was administered in late Spring 2023. Like with the pre/post content survey for the narrative study, the questions for the chemistry content survey were taken from past AP Chemistry exams.[2] The chemistry content survey can be found in Appendix P.

End-of-Semester Surveys

At the end of each semester, including the summer session, all graduate students in the MS program were asked to complete a survey evaluating their experience with content courses, their thoughts on the effectiveness of the MS program, and how they perceived changes in themselves as a result of the MS program. A general format of the end-of-semester survey can be found in Appendix Q.

Attitude toward Subject of Chemistry Inventory (Pre/Post)

The ASCI is an instrument that measures students' attitudes toward chemistry.[64] In order to better understand how the summer research experience on the SDSU campus impacts teachers' attitudes toward laboratory research, the instrument was adapted to measure the participants' attitudes toward chemistry laboratory research. The ASCI contains twenty items, each item containing two words separated by a seven point scale.[64] Respondents are asked to "position themselves…between two polar adjectives" in a manner that best describes their attitude toward chemistry, or in our case chemistry laboratory research.[64] The ASCI was administered prior to and after the participants' experiences in two consecutive on-campus summer sessions at SDSU. The ASCI can be found in Appendix R.

Post-Campus Summer Survey

The Post-Campus Summer Survey allowed participants in the on-campus summer session to voice feedback about their experience in the research laboratories on campus. In this survey, the participants were asked to describe if there were any changes in their view of the research process after spending time in a research lab. Teachers also reflected on how the on-campus research experience has influenced how they think about laboratory work in their own classrooms. The Post-Campus Survey can be found in Appendix S.

Course Feedback Member Checking Survey

A survey was sent out to all participants and alumni who participated in program courses from Fall 2021 to Spring 2023 in order to collect feedback on course benefit and value for money (cost-benefit) data that resulted from end-of-semester surveys. The Course Feedback Member Checking Survey can be found in Appendix T.

<u>Alumni</u>

Alumni Survey

In early Fall 2022, a survey was sent to MS alumni who completed the MS program to learn more about their experience in the MS program and to see if their responses are consistent with those of the current MS program participants. Alumni also shared how their time in the MS program impacted their professional development. The Alumni Survey can be found in Appendix U.

Graduate Teaching Assistants (GTAs)

GTA Survey

After each of the summer sessions, the GTAs who worked with teachers in the lab during their on-campus research experiences were asked to complete a survey about their experience. Learning outcomes for both the teachers and the GTAs were discussed. The GTA survey can be found in Appendix V.

Data Analysis

All interviews were transcribed verbatim, then revised through intelligent transcription to remove fillers and pauses. The Zoom teaching observations were guided by the Danielson rubric.[62] Observation notes were then qualitatively coded. All surveys, interviews, journals, discussion forums, and modules were qualitatively coded. Creating differentiated codes allows qualitative researchers to organize the data set meaningfully, while finding relationships and meaning within and across data sources that result in overarching themes.[65] The patterns that emerge from the data during analysis demonstrate trustworthy evidence of the validity of the codes and themes.[66]

Three codebooks were developed in order to organize and analyze the data for this project. The first codebook involves codes that describe all aspects of the teachers' involvement in the MS program. These codes were created through an inductive process. Codebook 1 was used to analyze all data sources, except for the modules and teaching observations. Codebook 1 can be found in Table 4. Examples are provided for each general code and ID codes from Tables 2 and 3 are used to identify each data source.

Table 4. Research Codebook 1: General Codes

Research Codebook 1: General Codes			
Code	**Abbreviation**	**Description**	**Example**
Attitudes	A-p	Discusses attitudes held by teachers, including teaching philosophy, confidence, excitement, concerns, goals, motivations, and desire for growth *prior to their involvement in the MS program.*	I would have described the work as very serious and not at all humorous or spontaneous. I probably would have pictured it as routine and monotonous. (PCSS)
	A-c	Discusses attitudes held by teachers, including teaching philosophy, confidence, excitement, concerns, goals, motivations, and desire for growth *during or after their involvement in the MS program.*	The experience really showed me how creative the [research] process can be. It is a serious business, but it is not at all monotonous or dry. (PCSS)
Knowledge	K-p	Discusses knowledge possessed by teachers	I never really understood those

		before entering the program.	concepts before, I just skimmed over the top of them with my students, introducing formulas and not really thinking about the "why". (EOS)
	K-c	Discusses knowledge that teachers gain about chemistry content and pedagogy through the program and its coursework.	I learned a LOT more about entropy and about the 1st and 2nd Law of Thermodynamics. (EOS)
Skill	S-p	Discusses skills held by teachers prior to entering the program, including research and pedagogical skills.	I want to gain experience with analysis equipment that I don't normally have access to. (SJ)
	S-c	Discusses skills developed through the program, such as time management skills, research skills, and the ability to apply knowledge to their own teaching	Throughout my time in the lab, I learned so many new techniques and ideas that would be relevant to improving the lab experiences of

		context.	my own students. (SJ)
Teaching	T	Discusses impact of program (gain of knowledge and skill) on professional teaching, including curriculum, pedagogical techniques, and activities.	I would like to introduce more reading into my classroom and reading Gribbin's book gave an idea how. (DF)
Feedback	F	Discusses feedback the teachers have provided regarding program logistics, course delivery, course assignments, etc.	I would prefer if all of the courses had a component where the instructor was required to make a video going over the concepts if it is a chemistry content class. (EOS)
Modules	M	Discusses teachers' experience with module assignments.	This module has helped by completely thinking through a topic and why it's important instead of just teaching it because it comes next or because it is in the standards.

			(MS)
Background	B	Discusses teachers' experiences prior to the program, including teacher preparation, science education, and teaching experience.	I taught high school chemistry at a private school. I started an AP Chemistry program and wanted [a] graduate degree to eventually teach for college credit. (AS)
Interaction	I	Discusses participant-participant interactions and instructor-participant interactions. Shares networking that occurs through program and how teachers interact with each other.	I feel like I have a new network of teachers that I can tap into when I am struggling with ideas for how to teach a concept. (EOS)
Experience	E	Discusses experience of teachers and TAs in program activities and courses. Also includes experiences that coincide with participants'	I found so much benefit in the time working in the lab and seeing how actual bench chemistry looks on a day to day basis. (SJ)

		enrollment in the MS program.	
Goals	G	Discusses participant goals for their time in the program.	I have a goal to gain a better understanding of certain higher-level lab technologies/procedures. (SJ)
Reflection	R	Discusses how teachers reflect on their experience with course materials and the impact of the program itself.	The forums have allowed me to be more reflective and try to approach my teaching style in a slightly different way this year (DF)

The second codebook was developed by a deductive process in order to organize components of PCK, as defined by Lee & Luft.[41] Each of the seven components of PCK forms a differentiated code. The codes, along with abbreviations, descriptions, and examples, can be found in Table 5. Codebook 2 was used to code the modules, pedagogical course reflection, teaching observations, teaching observation surveys, and a portion of the exit interview.

Table 5. Research Codebook 2: Pedagogical Content Knowledge (PCK) Codes

Research Codebook 2: Pedagogical Content Knowledge (PCK) Codes			
Code	**Abbreviation**	**Description**	**Example**
Knowledge of science	KoSc	Discusses science content, scientific practice, the nature of science, scientific progress	With this class I have a deeper understanding of how to explain the atomic theory and we can go more in-depth now rather than touching it briefly. (DF)
Knowledge of goals	KoG	Discusses scientific literacy, real-life application, integrated understanding	This course has made me to think about my curriculum and where I could improve it so it becomes more meaningful for students as they venture out on adventures after high school. (DF)
Knowledge of students	KoSt	Discusses different levels, needs, interests, prior knowledge, ability, learning	When I am learning and a student, I am more aware of the process of learning by my students

		difficulties, misconceptions	and empathetic to the trials of learning new things. (EOS)
Knowledge of curriculum organization	KoCO	Discusses state and local standards, state and local standardized tests, making connections between lessons and units, organizing lessons in specific order, making decisions about what to teach, flexible design	I am taking a fresh look at my curriculum and trying to find areas where I can do a better job of explaining, demonstrating, or letting the students "discover" something with guidance from me. (EOS)
Knowledge of teaching	KoT	Discusses various teaching methods, use of motivating activities, ability to select effective activities	The Teaching Strategies course introduced me to a wide variety of teaching strategies and ideas that could apply to any class. (EOS)
Knowledge of assessment	KoA	Discusses formal and informal ways of assessment, skills for students' discussion and	I am more deliberately incorporating discussion into the courses I teach. Discussion can help

		questioning, immediate feedback	students formulate ideas, revisit or reconsider material, apply concepts, and has the potential to help students connect with the material on a more personal level. (DF)
Knowledge of resources	KoR	Discusses materials, activities, multimedia local facilities, laboratory technology, science magazines	I have benefited a lot from my interaction with [M.S. participants]. The resources, ideas, comments, activities, etc., shared [in online discussions] have given new insights on how to hone my teaching. (DF)

The third codebook was created by an inductive process to analyze feedback collected through multiple sources on aspects of the MS program. This codebook further analyzes the Feedback code from Codebook 1. Codebook 3 was used to analyze all data sources, except for the modules, when relevant. Codebook 3 can be found in Table 6.

Table 6. Research Codebook 3: Feedback Codes

Research Codebook 3: Feedback Codes			
Code	**Abbreviation**	**Description**	**Example**
Assignment Feedback	AF	Discusses feedback related to course assignments.	Some of the discussion board questions could have been more tailored to teaching. (EOS)
Course Feedback	CF	Discusses feedback related to course structure and content.	The courses challenged me and helped me to see holes in my knowledge and elevated my content knowledge (EOS).
Program Feedback	PF	Discusses feedback related to the overall program.	The critical examining of my practice while also applying new content has been the hallmark of this program in general (EOS).
Course Delivery Feedback	CDF	Discusses feedback related to course delivery, including instruction methods and class website.	I would prefer if all of the courses had a component where the instructor was required to make a video going

			over the concepts if it is a chemistry content class. (EOS)
Logistical Feedback	LF	Discusses feedback related to logistics and communication with program participants.	One of the things I might change is to ensure some kind of uniformity between different classes with respect to how class information is organized and communicated. (EOS)

In the midst of data analysis, it became clear that I needed a fourth codebook to explain how teachers are being transformed through the MS program. Codebook 2 describes aspects of PCK, but these aspects were only relevant when teachers were actively applying their knowledge to teaching situations, such as through the modules or teaching observations. In order to understand how teachers were displaying combinations of knowledge bases, a codebook was developed to document the source of motivation for participants' comments. Codebook 4 helped demonstrate the intention behind what teachers are learning or gaining from the MS program. All sources of data except the modules, teaching observations, and GTA survey were analyzed using Codebook 4 (Table 7).

Table 7. Research Codebook 4: Source of Motivation Codes

Research Codebook 4: Source of Motivation Codes			
Code	**Abbreviation**	**Description**	**Example**
Learning-focused	L-f	The motivation behind the participants' comments is focused on their own learning.	I've rediscovered my love of being a learner myself, and of being challenged to learn hard things. (EOS)
Student-focused	S-f	The motivation behind the participants' comments is focused on their students' learning.	Through better understanding these concepts, I feel that I would be better able to explain them to students and help them make the connections to the significance they held in the history of science. (DF)
Teaching-focused	T-f	The motivation behind the participants' comments is focused on their teaching.	I think that my big takeaway is rethinking with more detail how I would deliver this unit in the next academic year in a more engaging way. (DF)

The codes and themes will be discussed in depth in subsequent chapters.

Frequency of codes was determined by dividing the total number of appearances of a singular code by the total of all separately coded responses within the dataset. Frequencies will be discussed further in the data chapters.

Data analysis for methods seeking to measure content knowledge change involved assessment through academic scoring. The Chemistry Content Exam and Chemistry Content Survey were scored using the official Scoring Guidelines of AP free-response questions from past exams.[2] These methods were used in order to measure chemistry content knowledge change that occurred due to MS program content courses.

Statistical Analysis

Statistical analysis by *t*-test was used to compare pre/post data for the ASCI. All statistical analysis was used to support qualitative data in this project.

Validation Methods

Creswell & Poth define validation as “an attempt to assess the ‘accuracy’ of the findings as best described by the researcher, the participants, and the readers/reviewers.”[67] Multiple validation methods were utilized in this study from each of the perspectives defined by Creswell & Poth:

- From my perspective as the researcher, I have used multiple data sources and methods in order to triangulate the data and ensure the validity of the themes that were constructed through this analysis.[67, 68]
- In the introduction chapter, I have disclosed any bias and values that I bring to this study.

- In order to involve my participant, I engaged with my narrative participant through member checking.[67] I sent my observations to Taylor, my narrative participant; however, I was not able to obtain their response to corroborate my findings. The course feedback member checking survey allowed for corroboration of general content course feedback. Member checking responses are included in Chapter 6: Course Feedback.
- I have also been involved with the MS program as a GTA and am able to interpret participant experiences through my own observations.
- Through the progress seminar and committee meetings, I have invited external reviews of the structure of this study and interpretations of the resulting data.[67]

Reliability Methods

According to Creswell & Poth, reliability "refers to the stability of responses to multiple coders of data sets."[67] A reliability study involves multiple coders of a single data set using the codebook created by the primary researcher to assess if there is at least 80% agreement among researchers.[67, 69] I have conducted a reliability study for each codebook and determined that intercoder reliability is 82.6%.

CHAPTER 4: NARRATIVE PARTICIPANT

Narrative Study

When designing this study, it was important to me to follow participants' experiences through the program to better understand what teachers are gaining from the MS program. Are they gaining PCK? Are they improving their chemistry content knowledge? Are they becoming more effective educators? To answer these questions, it would be necessary to follow a single participant's journey through the program from start to finish. The initial design for this project involved a case study approach to follow multiple teachers through their two-year experience in the MS program. Upon recruitment, there was low response and only one teacher was successfully recruited. Partway through the semester, I recruited another teacher, but they no longer fit the recruitment criteria after a period of two months of the study. Because of these changes, I decided to shift to a narrative approach.

Study Population

Through this narrative design, one teacher was followed through their experience in the MS program. To maintain confidentiality of this teacher's identity, I will use the pseudonym Taylor and use they/them pronouns when referring to the narrative participant. Taylor is a veteran teacher coming from a suburban school in a Midwestern state. By conducting individual interviews and virtual teaching observations, monitoring content knowledge change, and periodic surveying of course and MS program experiences, I was able to gather data representative of Taylor's comprehensive experience to form a narrative. More details of Taylor's background will be shared in this chapter, as well as their experiences through the program.

Timeline

Data was collected for the narrative study over a period of two years, from Fall 2021 to Summer 2023, across the participant's entire experience in the MS program. Table 8 displays the timeline for all data collection methods. Taylor participated in each of the program courses listed in Table 8 and participated in additional data collection separate from program data collection methods. These methods are listed as "Narrative" in Table 8.

Table 8. Term Breakdown of Narrative Participant Data

Term	Course/Setting	Methods ID Codes
Baseline	Narrative	CE, IS, II, TO, OS
Semester 1 (F21)	Narrative	TO, OS
	CHEM 770	TS, MS, DF, EOS
	CHEM 771	CoRe, MS, EOS
Semester 2 (Sp22)	Narrative	I (2), TO, OS
	CHEM 772	CoRe, TS, MS, EOS
	CHEM 778	MCR, EOS
Summer 1 (Su22)	Narrative	I
	CHEM 776	SJ, ASCI, PCSS, EOS
Semester 3 (F22)	Narrative	I (2), TO, OS
	CHEM 774	CoRe, MS, EOS
	CHEM 775	TS, MS, EOS
Semester 4 (Sp23)	Narrative	I, TO, OS

	CHEM 773	DF, CoRe, MS, EOS
Summer 2 (Su23)	Narrative	I
	CHEM 776	SJ, ASCI, PCSS, EOS
Exit	Narrative	CE, ES, EI

Baseline

Many data collection methods served to create a baseline for any changes to content knowledge, PCK, or teaching effectiveness due to Taylor's participation in the MS program. The baseline data is presented chronologically. The initial survey served as a method of learning more about Taylor's background and goals for the MS program. The pre-content exam provided a baseline for Taylor's chemistry content knowledge. The initial interview followed up on their responses to the initial survey and determined Taylor's academic, professional, and personal goals for the MS program. The observation and pre/post observation surveys provided baseline data for Taylor's teaching confidence and effectiveness prior to taking MS program courses.

Recruitment

Upon recruiting participants for this study, Taylor sent me an email with their completed consent form with the following note:

- "I really like the potential impact your research can have and am interested in participating."

This message set the tone for the researcher-participant relationship and indicated the participant's interest in the program's impact.

Initial Survey

After receiving Taylor's consent form, I sent them a link to the initial survey. The initial survey gathered information about the participant's educational and teaching background, their thoughts on their current teaching effectiveness, and what their goals were for the MS program. The initial survey was analyzed using Codebooks 1 and 4, with results shown in Table 9 and Table 10.

Codebook 1

Table 9. Initial Survey Coding Frequencies – CB1

Code	**Abbreviation**	**Frequency of Responses (*N* = 24)**	**Percentage of Total Responses (%)**
Attitudes	A-p	7	29.2
Knowledge	K-p	3	12.5
Skill	S-p	3	12.5
Teaching	T	4	16.7
Background	B	2	8.3
Goals	G	1	4.2
Interaction	I	2	8.3
Reflection	R	2	8.3

This survey served as my introduction to who Taylor was as a science teacher as they entered the program.

Background

In discussing their science background, Taylor stated that they completed a bachelor's degree in Chemistry Education nine years prior to enrolling in the MS program, but otherwise did not have "much of a background in science." Taylor detailed the impact their mentor had on them during their undergraduate experience:

- "Much of the growth in my teacher prep program came from my Chem Ed mentor, who exposed me to all kinds of research and applicable pedagogical practices relevant to my field."

Taylor then described their background in teaching, first by discussing the history of their teaching context:

- "My first 3 years teaching, I was at a small rural school."
- "The past 6 years I have spent at a much larger school."

Then, Taylor detailed which subjects they have taught at their first and second schools, respectively:

- "I…was responsible for Chemistry, Physics, 9th grade science, Astronomy, and Geometry."
- "I…have predominantly taught Chemistry at various levels (honors, general, concepts)."

Teaching and Reflection

Before starting the program, Taylor shared their motivation for teaching high school chemistry and how that motivation affected their instruction, relating to prior knowledge and attitudes and reflection. Taylor's teaching motivation showed aspects of PCK, including KoCO and KoG.

- "Desire to help kids develop a lens of viewing the world that lets them see/understand it in ways they hadn't been aware of…As I learned more, I felt I could make a significant contribution toward improving the state of science education in our country."
- "Additionally, reviewing so much research during college exposed me to the gaps in effective teaching based on traditional teaching practices."
- "Wanting to make an impact in science ed has caused me to constantly learn, reflect, and try new things in my classroom."
- "Because my teaching relies heavily on students generating, sharing, and evaluating their thoughts, I believe it's most appropriate at the high school level. At this level, I'm able to have conversations and engage in scientific argumentation in ways I don't think I would be able to at lower levels."

Upon discussing their teaching motivation, Taylor also described what they do in their classroom to align their instruction with their teaching philosophy.

- "To help students develop this scientific lens of viewing the world, I often place students at the center of their learning. I believe it has led me to subscribe to a constructivist approach."

On a scale of 1 to 6, Taylor ranked their teaching effectiveness as a 6 and explained their rating with the following statements. These statements were also coded for prior attitudes and knowledge.

- Being "experienced in questioning strategies [and] discussion techniques. I feel confident designing and implementing lessons that put student[s] at [the] center of learning. I am a confident teacher but never willing to accept my current teaching is as effective as it can be."

- "Being informed with past/current research."

Taylor also shared what limits their teaching effectiveness, relating to teaching and interactions.

- "Out of my control: Typically colleagues who are not as familiar with research/effective pedagogical practices and department/school requirements that rely on commonalities between department members that end up placing a restraint on me with respect to how I can teach."
- "In my control: Sometimes spreading myself too thin. Get caught up in too many ideas instead of targeting my focus toward 1-2 ideas that I can devote time/energy toward."

Knowledge, Skill, and Attitudes

To gauge Taylor's current level of content knowledge and pedagogical skill, they were asked to rate their confidence teaching advanced chemistry concepts on a scale of 1 to 6. First, Taylor was asked to determine what concepts qualify as "challenging" in their classroom using their pedagogical skill.

- "The amount of prerequisite knowledge is required to understand it. The level of math involved. Whether not the concept is predominantly abstract or concrete."

Taylor then rated themselves as a 6 and explained why, highlighting their KoSt:

- "I like teaching challenging topics because I'm usually able to view it from the point of the student since it's not yet part of my experienced content knowledge. This helps me anticipate questions and design lessons in ways that I know will

> bring out misconceptions, because I had already encountered those misconceptions when trying to learn it."

In terms of what makes them most effective as a teacher, Taylor stated that it was "being reflective, and [having] a genuine desire to learn."

Goals and Interactions

One goal of the program is for teachers to be able to make changes to their teaching based on what they have learned through program courses and experiences. Before entering the program, Taylor indicated that they were "very comfortable making changes" to their teaching if they "know there is a legit reason for this change." When making changes in their classroom, Taylor mentioned interacting with colleagues through conversations and comparing new changes to research and what they "know to be true about how learning works."

The final question of the survey asked Taylor to indicate what they were looking forward to most about this program:

- "I'm looking forward to becoming more fluent in incorporating the science practices (NGSS) and how I can help my kids develop skills instead of just content knowledge. Also, looking forward to working and communicating with other passionate educators!"

Codebook 4

Codebook 4 then allowed me to break down the teacher statements by source of motivation. Each comment was assessed to determine the focus of the comment, either focused on the participant's learning, their students' learning, or the participant's teaching. Coding frequencies are displayed in Table 10.

Table 10. Initial Survey Coding Frequencies – CB4

Code	**Abbreviation**	**Frequency of Responses (*N* = 24)**	**Percentage of Total Responses (%)**
Learning-focused	L-f	8	33.3
Student-focused	S-f	6	25
Teaching-focused	T-f	10	41.7

Taylor's responses to the initial survey included motivations related to their learning and teaching, as well as their students' learning.

Summary of Initial Survey

Through the initial survey, I learned about Taylor's background in science and education. As a veteran teacher, Taylor had spent almost a decade teaching high school science, with their most recent years focusing on chemistry courses. Prior to entering the MS program, Taylor's primary motivations for teaching included the following:

- Improving science education to help students develop a "scientific lens of viewing the world."
- Implement research-based teaching practices through "learning[ing], reflect[ing], and try[ing] new things in [their] classroom."
- "Place students at the center of their learning" by way of a "constructivist approach."

Taylor ranked their teaching effectiveness as a 6 out of 6, stating that they are "a confident teacher but never willing to accept [their] current teaching is as effective as it can be." Taylor expressed an openness to learn and grow to become an even more effective teacher. Taylor also ranked their confidence teaching advanced chemistry concepts as a 6 out of 6, expressing a strong knowledge of their students and having "a genuine desire to learn."

Taylor communicated the following goals they had for their time in the MS program:

- "Becoming more fluent in incorporating the science practices" from NGSS.
- Helping students "develop skills instead of just content knowledge."
- "Working and communicating with other passionate educators!"

Taylor's responses demonstrated their motivations to gain knowledge and skills related to their own learning and teaching which would benefit their own students' learning as well.

Content Exam (pre-test)

The next data collection method to establish a baseline for Taylor's chemistry content knowledge was the pre-content exam. The full content exam can be found in Appendix E. Proctored via Zoom, Taylor was given the exam consisting of nine past AP Chemistry free-response questions related to each of the program's content courses.[2] During the examination period, Taylor asked one clarifying question and completed the exam in a little over 2 hours. The exam was scored using AP Exam scoring guidelines.[2] Scores for each question, course connections, comfort level rating, and confidence level rating data are shown in Table 11. The comfort level related to their comfort with the content of the question. The confidence level related to the participant's confidence with the accuracy of their answer.

Table 11. Pre-Content Exam Score and Analysis for Narrative Participant

Question	Course Connection	Point Total	Comfort Level (1-6)	Confidence (1-6)
1	CHEM 774	2/4	2	2
2	CHEM 775	0/3	1	1
3	CHEM 774	4/7	4	3
4	CHEM 770/771/773	6/10	4	4
5	CHEM 770	6/6	6	5
6	CHEM 772/774	3/5	5	5
7	CHEM 773	1/3	4	3
8	CHEM 772	4/10	5	4
9	CHEM 775	2/2	5	6

The overall score for Taylor's pre-content exam was 29/50, which demonstrates their baseline chemistry content knowledge, or KoSc, as a component of their PCK. They described being more comfortable with the content and having higher confidence in the accuracy of their answer on questions for which they earned more points, which indicates their attitudes aligned with their ability. Specific errors in calculations and explanations will be discussed when comparing changes between the pre- and post-content exams later in the chapter.

Initial Interview

Immediately following the conclusion of the pre-content exam, I conducted the initial interview with Taylor to follow up on their responses to the Initial Survey and to discuss their motivation for completing this degree through this specific MS program, as well as what knowledge they hoped to gain through the MS program. Their responses were coded using Codebooks 1 and 4.

Codebook 1

Coding frequencies for the initial interview for Codebook 1 can be found in Table 12 below.

Table 12. Initial Interview Coding Frequencies – CB1

Code	**Abbreviation**	**Frequency of Responses (*N* = 43)**	**Percentage of Total Responses (%)**
Attitudes	A-p	5	11.6
Knowledge	K-p	3	7.0
Skill	S-p	4	9.3
Teaching	T	4	9.3
Background	B	5	11.6
Goals	G	12	27.9
Interaction	I	1	2.3
Reflection	R	9	20.9

Attitudes (A-p)

Taylor shared their attitudes toward starting the MS program, focusing on becoming a better educator.

- "I'm excited because [the MS program] can't make me a worse teacher. I feel it can only make me better."

Taylor shared their attitudes toward their teaching effectiveness, including confidence in their pedagogical skill (KoT).

- "I really enjoy probing for deeper understanding. I think I'm a really good questioner. I think I'm good at improving or working on the fly based on student responses, so without having necessarily a script I know I'm aware of certain misconceptions and what a certain answer implies about their current level of understanding…I feel like I'm an effective teacher partly because I'm confident in my skills but also partly because of what I expect" from students.
- "I feel like I am confident in my ability to create situations or opportunities where kids can take small chunks of understanding that inevitably build up to that difficult concept that we're claiming."

In terms of their confidence in teaching challenging chemistry concepts, Taylor rated themselves a 6 on a scale of 1 to 6. Taylor discussed their attitudes toward completing the MS program relating to their professional and personal goals, especially related to finances.

- "I am worth more than what I am currently making with just a Bachelor's degree and then I talked to other teachers that have been teaching 20+ years and they're making almost twice as much as me and yet I know that they're not twice as an effective teacher as I am… Do I want to get paid more? Absolutely, who doesn't? I'll be making significantly more money when I graduate from this [MS program]…I suppose having a kid plays a role, but I want to be able to improve my ability to contribute to supporting my family from a financial point of view and this will help accomplish that."

Taylor also shared attitudes relating to their personal goal to regain professional passion through completing the MS program.

- "Going into my tenth year, I feel like I'm hitting a point where that constant motivation and constant passion and constant energy that I had my first five years – I can feel how other teachers that are older than me begin that process of complacency. I can almost feel myself being okay with everything and I don't want that. I want to evolve, I want to change, I want to become better…There's an inner growth that I want to have personally as a teacher, that I wanted to pursue to lead to a greater sense of purpose and a reignition of interest and passion…By completing this program, I'm intending for it to make me a more effective teacher but I also hope that it helps reignite a passion in me that is purely a subjective thing. It's an inner thing that you're excited to share and develop this knowledge with kids that I could feel myself not being as excited in the past maybe two years."

Summary of Attitudes (A-p)

Taylor's attitudes toward starting the MS program primarily related to their professional and personal goals for the experience. The main themes for attitudes were:

- Although Taylor described feeling confident in their current teaching effectiveness, they shared their excitement for becoming a better teacher through the MS program.
- Taylor discussed their attitudes related to their motivations for completing the MS program, including financial goals and a professional "reignition of interest and passion."

<u>Knowledge (K-p)</u>

Taylor discussed their desire to gain chemistry content knowledge through the MS program requirements. They expressed the positive impact increased KoSc would have on their teaching approach. Their combination of their KoSc, KoSt, and KoT demonstrates their awareness of how they could improve the quality of their PCK. They also describe how increased knowledge would positively impact their teaching confidence.

- "I definitely hope to gain a deeper understanding or a deeper comfort level with content. Just purely at the content level, so not even from a teaching point of view, just from an understanding chemistry point of view. Even though there is a level of understanding in this content that I would not expect from my kids, knowing that stuff is important for a number of different reasons, but it will allow me to grow in my ability to become aware of misconceptions and develop questions whether they're on assessments or on the fly, the better I understand something, the more ways I can approach it and I'm hoping that gaining that deeper content knowledge will allow me to approach things in ways that I may not have even considered in the past because I didn't have those pathways of understanding prior to that, so it'll help me make more connections."

- "In addition to gaining a greater sense of content knowledge, like for example - this is more so true in the Honors stuff - with bonding and with atomic theory more so and the quantum stuff, helping students – me gaining a deeper understanding of the historical impacts or timeline of quantum theory but also its impacts at the practical level is something by understanding it better I'm going to be able to create a better pathway than what I currently do and that is going to allow me to be more confident in executing it."

When describing how they consider making changes to their teaching, they first mentioned its alignment to their knowledge of learning and chemistry education research.

- "The first little barrier would be does this align with what I already know to be true about learning and about my knowledge of chemistry research."

<u>Summary of Knowledge (K-p)</u>

Taylor discussed their hopes for the program in terms of knowledge gain. The main themes for knowledge were:

- In terms of knowledge, Taylor described hoping to deepen their level of chemistry content knowledge through the MS program. They described how improvements to their KoSc would positively impact their teaching effectiveness, revealing a combination of PCK bases. Taylor stated that improvements to their KoSc would also improve their KoT, which would improve the overall quality of their PCK.
- Taylor discussed their criteria for making changes to their teaching approach, which relied on their knowledge about learning and chemistry education research.

<u>Skill (S-p)</u>

Taylor attributed their high level of teaching confidence, which they rated as a 6 on a scale of 1 to 6 for challenging chemistry concepts, to their pedagogical skill. Connecting to their A-p, they described confidence due to their pedagogical skill.

- "When I'm trying to learn a difficult concept or teach a difficult concept, I always try to break it down into first principles – in other words, what is really the issue going on here, what is the prerequisite knowledge that I need to have here [*motions low*] in order to understand this and this and this [*motioning upward*] and building up to the concept…I am confident in my ability to create situations or opportunities where kids can take small chunks of understanding that inevitably build up to that difficult concept that we're claiming."

Taylor also discussed the research skills they hoped to gain through the MS program (KoSc), particularly research they hoped to carry out in their own classroom.

- "There is no shortage of ideas that I have [for research] and I might implement these ideas, but if there's one area that I feel like I really could improve on is [to] follow through on [these ideas] in a way that allows you to evaluate their effectiveness…I would like to develop a better set of skills that allows me to not only generate, but evaluate the effectiveness of a decision that I've made in my classroom…whether it's pedagogical or content and I think that gets answered by actively doing research."

Taylor described their desire to improve their skill for creating a positive learning environment (KoG).

- "I hope to gain a greater ability to create a passionate and welcoming and engaging environment that is dedicated to welcoming students in a way that inspires them to see the world through a different lens."

Finally, Taylor discussed their goal to develop their time management skills.

- "I'm really looking to develop my time-management aspect of things. I can waste time as good as anybody [laughs] and I can procrastinate as good as anybody."

Summary of Skill (S-p)

Taylor reflected on their current level of pedagogical and research skills and discussed their hope to further develop these skills through their experience in the MS program. The main themes for their skills were:

- Taylor described feeling confident with their current level of pedagogical skill in terms of teaching challenging chemistry concepts.
- Taylor hoped to develop better research skills to be able to carry out research in their own classroom to evaluate the effectiveness of their teaching choices.
- Taylor wanted to gain skills to create a positive learning environment for students, again demonstrating their student-centered teaching philosophy.
- Taylor hoped to develop better time management skills through their participation in the MS program.

Teaching (T)

When discussing the multiple chemistry classes that they teach, Taylor reflected on the difficulty of adjusting their teaching based on the course curriculum and the students in their class. These comments relate to Taylor's KoT, KoCO, and KoSt, showing that they combine these PCK bases when teaching their students.

- Having a wide range of students "has its difficulties, [like] reminding myself to switch modalities between my expectations of where students can think, especially after an Honors class going directly to a concepts class. I can make certain assumptions and have certain expectations in the Honors class that I absolutely would not have those same assumptions in the concepts class, or even general, and sometimes transitioning from one to the next can be difficult when you're just going from one hour to the next hour."

Taylor discussed their expectation that the MS program will help them improve their teaching effectiveness.

- "I genuinely think [the MS program] is going to help me become a more reflective, better teacher and in doing so it's going to allow me to build things, create things, engage with my students in ways that I may not have otherwise and as a result be willing to share those things at a much broader level."

Taylor shared their teaching philosophy regarding their goals for student learning (KoG).

- "I think by taking this program in regard to helping students develop a better lens - not a better lens - but a different lens of viewing the world from a scientific point of view. It's just a fancy way of saying helping students become more scientifically literate."

Taylor reflected on their thought process for making pedagogical changes and shared their definition of a "legitimate reason" for making changes to their teaching (KoT). They also demonstrated their pedagogical alignment with research-based teaching practices.

- "Nothing that I do I feel so confident that it's the best version of whatever it is that could possibly be, it's just that if I'm going to do something, I want to make

> sure there's good reason for me to do it…I would say [the teaching change] has to make sense to me, be in line with what I already know to be true, or if none of those things happen, then I need to be taken through the reasoning process why this makes sense, rather than just told that this is a better way."

<u>Summary of Teaching (T)</u>

Taylor reflected on their current teaching practice and discussed their goals for the MS program related to their teaching. The main themes for this code were:

- Taylor teaches a variety of chemistry courses and reflected on the difficulty of adjusting their teaching during brief transitions between classes. Taylor demonstrated their need to combine their KoT, KoCO, and KoSt when teaching students with different levels of knowledge, which would improve the overall quality of their PCK.
- Taylor believed that the MS program would allow them to become a better teacher, which would positively impact their students' learning. Similarly, they hoped the MS program would allow them to help students become more scientifically literate.
- When discussing their thought process for making pedagogical changes, Taylor discussed their reliance on research-based practices, ensuring that these changes are supported by research.

<u>Background (B)</u>

When discussing their educational background, Taylor shared their process of deciding to pursue chemistry education as their undergraduate major. Their decision related to interest in science and learning and having a positive faculty mentor experience.

- "I don't ever remember having a specialized interest in science until I was probably a freshman or sophomore in college. That was partially sparked by, and fueled by, my mentor in college who was a chemistry professor who obviously taught chemistry but also taught the chemistry education class for diving deep into research. Unlike a lot of the professors who are geared toward research in chemistry he was geared toward research in chemistry education and so the personality types clicked but also the exposure to the research and just learning more about the subject opened up a new lens for me, a new frame of mind, at I think a big turning point in my college career. Freshman year was just– you know there's all kinds of social things going on and you're not really sure where you're going with your life and it could have gone a number of different routes and to be taken in by this person and also just showing a genuine interest for it and then as I progressed throughout college and once I declared a major for that program, that was all well and good, I started to notice that I started to become a lot more interested in deeper thinking about things from first principles point of view, really getting into space stuff. I was really curious about how the world works as well as how people learn. In my mind it was a really nice merging of psychology, which I really like, but also more so developmental psychology, learning, but also physics and chemistry."

Taylor then shared their teaching background in terms of their current teaching context.

- "I'm going into my 7^{th} year [at their current high school]. I've primarily taught chemistry. I think there was one year where I had to teach 9^{th} grade physical science, but it's pretty much just been chemistry. For the past 3 years, I've been able to teach general chemistry, which is obviously the most highly attended class as well as Honors chemistry. We don't have AP or IB or anything like that. [Honors] is the highest-level chemistry that we have. This past year I taught Honors, general, and concepts. It was pretty interesting to get all three levels [*motioned tiers*]. Concepts would be those who really struggle with mathematical reasoning, generally have weaker science reasoning skills, things like that. This year is the same schedule, so concepts, general, and Honors [*motioned tiers upward*]."

Since this interview took place in August 2021, Taylor then described any modifications to their teaching context due to COVID restrictions/guidelines.

- "We are in person five days a week. Masks are recommended. I don't know the exacts on this if somebody has to go out because of COVID or a number of kids have to leave, then I imagine there will be some kind of hybrid scenario, but it won't be to the extent that it was last year where over half of my kids are at home and half of my kids are here and trying to do that simultaneously. If I'm in that situation – which I'm assuming I inevitably will be – the fact that I already have so many filmed labs and videos and I'm just naturally a lot more comfortable with the use of a webcam while teaching, I'm not going to see it as a significant barrier. As of right now, it's full time five days a week in person."

Taylor attributed their student-centered teaching approach to professional training they have completed.

- “This is partly due to my modeling instruction training just before my first year of teaching – that’s been my philosophical lens through which I view my teaching is providing students with a pathway that is not 100% reliant on me.”

Taylor then reflected on their teaching effectiveness. On a scale of 1 to 6, they rated themselves as a 5 due to their experience and interactions with students. They discussed their teaching effectiveness for two teaching contexts: to a full class of students and one-on-one.

- “In a class of 35 the managerial [or] logistical aspects of it can almost get into the way of the pedagogical stuff, like the techniques and the questioning and the route that you’re trying to get kids to go on, and it has nothing to do with necessarily your effectiveness as a teacher. It depends on what you define as a teacher and I think most people would agree that part of being a teacher is a natural manager of things, so if that were the case then I would still be confident throwing myself in that 5 range. But even when I’m talking to a small group or one-on-one, I really enjoy probing for deeper understanding. I think I’m a really good questioner. I think I’m good at working on the fly based on student responses, so without having necessarily a script I know I’m aware of certain misconceptions and what a certain answer implies about their current level of understanding…I feel like I’m an effective teacher partly because I’m confident in my skills but also partly because of how I try to get my students to attain understanding that does not rely upon just my knowledge of their interaction with both my knowledge and questioning and their willingness to reflect on their own ideas. And I feel like that leads to a deeper understanding."

Summary of Background (B)

Taylor shared details about their educational and professional background prior to starting the MS program. The main themes for this code were:

- Taylor described their undergraduate educational background that led them to the field of chemistry education and prompted them to be interested in research-based teaching practices.
- Taylor described their teaching background at their current high school where they have taught multiple levels of chemistry classes over the course of seven years. They also discussed the impact of their modeling instruction training on their current teaching effectiveness.
- Taylor discussed the learning format for their school as of the Fall 2021 semester due to COVID restrictions or guidelines.
- Taylor was able to evaluate their current level of teaching effectiveness based on their ability to manage a classroom, question students to "probe for deeper understanding," and enable students to attain knowledge on their own. Their baseline level of teaching effectiveness was 5 on a scale of 1 to 6.

Goals (G)

Taylor discussed their goals for gaining both chemistry content knowledge and pedagogical knowledge during their time in the MS program. They described how gaining content knowledge would help them identify student misconceptions and support their development of pedagogical skills. They discussed how increased KoSc would impact their KoT and KoA.

- "I definitely hope to gain a deeper understanding or a deeper comfort level with content. Even though there is a level of understanding in this content that I would not expect from my kids, knowing that [content] will allow me to grow in my ability to become aware of misconceptions and develop questions whether they're on assessments or on the fly. The better I understand something, the more ways I can approach it and I'm hoping that gaining that deeper content knowledge will allow me to approach things in ways that I may not have even considered in the past because I didn't have those pathways of understanding prior to that. [Gaining content knowledge] will help me make more connections."

Taylor connected their goalsetting in their professional context to their goals for the program. By reflecting on their teaching and gaining research skills through the MS program, Taylor would be able to set and achieve personal learning goals at their school.

- The MS program "is giving me a more purposeful opportunity to reflect on why I do what I do. We're required at school to have these personal learning goals and team learning goals and they're even tied to the money that we get, but a lot of the times they just say 'write a goal' and there's not much support that goes with that. It's more so incumbent upon you to be aware of not only how to set a proper goal but how to execute on that goal and how to track data. Being involved in a class – or an overall program – where you're actively collecting data that you're analyzing in some way I'm more likely to engage in those reflective processes."

Connecting to Taylor's goals that were discussed in the skills section, they hoped to gain experience as an educator and researcher to benefit their ability to teach using a research-based approach.

- "I feel like doing research will be my opportunity to be both of those people simultaneously – the researcher and the teacher – and gain a perspective from the research side."

Taylor described their hope to reignite their passion for teaching that was negatively impacted by the COVID pandemic. They reflected on their experience teaching during the past two years and expressed a desire to find motivation for teaching again. They also expressed their KoSt by describing students' behavior during COVID.

- "By completing this program, I'm intending for it to make me a more effective teacher, but I also hope that it helps reignite a passion in me that is purely a subjective thing. It's an inner thing that you're excited to share and develop this knowledge with kids that I could feel myself not being as excited in the past two years. – Last year was really, really hard. I don't want to say not because of COVID – because it was because of COVID – but it was such a motivational depression. It was like seeing the worst in kids while also noticing or realizing that a lot of it wasn't necessarily their fault, but it was very easy to become pessimistic and falling down that rabbit hole more than a few times was really disheartening and made me not just lose motivation in chemistry education but lose faith in kids, really, and a willingness to follow through on things. I knew that that wasn't necessarily a rational position to take, me personally, but I felt that way. And there had to be something that made me feel that way. The program

I think will help reignite that, because I never had those thoughts prior to even two years ago."

Summary of Goals (G)

Taylor's goals for the program, whether focused on content knowledge, pedagogy, or personal mindset, all related to their ability to teach effectively. The main themes for Taylor's goals were:

- In combination with previously discussed codes, Taylor identified goals for the MS program including earning a raise, gaining research skills, and becoming a more effective teacher.
- Taylor discussed their goal for gaining content knowledge, which would impact their teaching confidence and effectiveness. This combines their KoSc and KoT, which demonstrates higher quality PCK.
- Taylor also set goals for learning how to set and reach professional goals, including gaining skills for evaluating the effects of their own teaching.
- Taylor shared their goal for reigniting their passion and motivation for teaching that was negatively impacted by the COVID-19 pandemic.

Interaction (I)

Taylor expressed excitement toward interacting with other science teachers in the MS program. They hoped to build professional and personal connections with these teachers, which could allow for professional development.

- "I'm also just excited to interact and argue in a respectful way and debate and engage with other teachers about things. Over the years I have built a pretty solid professional learning community in the online environment from teachers around the country and to be able to get to know other teachers that clearly have similar interests – otherwise they wouldn't be in this program – is something that I'm excited for as well."

Reflection (R)

Taylor reflected on their choice to pursue an MS degree at SDSU, which in part related to their ability to complete it online and be within a drivable distance to the campus.

- "Part of it was logistics. I love the idea that I could complete it mostly online and the fact that I would need to come to campus for two weeks two consecutive summers and the fact that it was only four hours away, so in other words it was very doable. I would not have done that if it was the exact same program was say in California."

They also discussed the fact that they came to SDSU previously for a chemical education conference and had interacted with the campus and an instructor for the program. They also communicated with an alumnus for the program, which supported Taylor's decision to choose the MS program at SDSU.

- "I had already been to SDSU. I had met Instructor A for example, very likable [person], but it's not like I know deeply about them or anything like that. The fact that SDSU was a host site for the ChemEd conference because it's such a widely known chemistry conference, at least in our world [laughs], told me something about how SDSU valued chemistry education, otherwise why would it be there?"

They also communicated with an alumnus for the program, which supported Taylor's decision to choose the MS program at SDSU.

- "I also knew at least one person who had already completed the program and I had asked him questions about it…and that reconfirmed my confidence in wanting to do this."

Taylor then reflected on their choice to do the MS program due to its focus on chemistry content. They aligned the program's focus with their background as a chemistry education major, which emphasized their goal to develop chemistry skills (KoSc) in conjunction with pedagogical skills (KoT).

- "I also liked that they emphasize the content aspect of it, that it wasn't an education degree necessarily. I really wanted chemistry with an emphasis in education, so it wasn't all content, it wasn't all education. The fact that it was specialized in chemistry education – which I think goes hand in hand with what inspired me in the first place to pursue a chemistry education degree in college, which I wasn't interested in becoming a chemist necessarily and I wasn't just interested in becoming just a teacher of anything – it was like there was this merging of chemistry and education that came together that I felt in just reading the course descriptions SDSU had to offer."

Taylor reflected on their desire to contribute to chemistry education through research and communication of ideas. They stated that the MS program would help them be able to reflect and share their ideas more effectively.

- "When I can I try to go to national level conferences or I'll present, but I'm also a monthly contributor to ChemEd X, which is a website designed for sharing ideas with chemistry educators around the world and not just exposing others to it but also to continue the conversation on it and building from it.[70] In and of itself, writing that is a reflective process in addition to sharing, so taking part in this program and developing myself and taking that next step I feel will allow me to share things with other teachers in ways that I would not have been able to do prior to taking this program, otherwise I would have done it in the first place."

In their response to the initial survey, Taylor discussed helping students develop a global scientific lens. They expounded on this teaching motivation by describing the necessity of being scientifically literate in modern times. Taylor shared their attitudes related to student learning, relating to their KoG as a component of their PCK.

- "The information landscape right now that my kids are in is so messed up in so many ways and tough to navigate and I feel like even the COVID vaccine or just COVID in general has really brought that to light where anybody anywhere can make a particular claim. I want to be able to do anything that I can to help my students have the necessary tools to be able to evaluate a claim without having to be a scientist. That they can assess the validity of not just claims on medicine, but claims on buying a house or whether you should buy this car at this time or if you should go on this trip or whatever it is – to having that reasoning ability to evaluate their decisions from a critical thinking [or] scientific approach. Having literacy and critical thinking skills is probably the biggest source of motivation for me. Plus I suppose on top of that just sharing my passion for chemistry in general, but I don't really care so much if my students graduate with an interest in chemistry per se, as much as it is that ensuring that everyone who leaves my class is at least – in the one year that I have them, to the extent that I can increase this, that they are better thinkers and more willing to engage in thinking than when they originally came into my class."

Taylor described how they could become more confident teaching challenging chemistry concepts, which focused mainly on having opportunities to reflect on their teaching choices (KoCO).

- "I think I could become more confident by reflecting on those pathways that I do create for those difficult concepts…Having opportunities to reflect deeply on why this and not that or why not insert this particular activity that I wasn't doing before right here instead of doing this particular activity and I think the program can help me do that with those reflective processes, those opportunities."

Taylor reflected on their desire to learn and face an intellectual challenge. The MS program would provide these challenges.

- "I've always been somebody who likes to learn regardless of what it is. It doesn't have to be science or whatever but there are these courses that I have to take and each of them is a challenge to some extent, whether that's a content knowledge challenge that I need to learn or it's a time management challenge or just a general responsibility challenge."

Taylor reflected on how the MS program would give them an opportunity to become more mentally resilient. They discussed their ability to support their family financially through completing the MS program, but it would also help them develop skills to successfully face challenges.

- "By having that greater sense of purpose, even if I look at it purely from a financial point of view – like 'hey you've got to do this and do it well in order to

> make more money to help support your family' – but I think looking at it even from that lens is like 'okay, this is a challenge in my life and doing things the way that you do them, approaching this challenge you have approached other challenges in the past is not going to suffice. In order to do this and do it well you have to take the next step in your life toward becoming more responsible, more aware. It's not just about you anymore.' I think that's where I see that personally where you're evaluating your life – where should my time best be spent? Or how do I spend that in order to still achieve the things I want to achieve? And I think it's going to help me develop personally in a way that gives me greater skills to tackle other challenges that are more so up here [*points to head*] rather than physical challenges. It's going to help me become more mentally resilient in ways that I think are going to help in other areas of my life."

<u>Summary of Reflection</u>

- Taylor discussed their choice to complete the MS program at SDSU due to its focus on content and emphasis on chemical education. They also reflected on their choice due to their awareness of the chemical education connections at SDSU, their communication with an MS program alumnus, and their ability to complete most of the degree remotely.
- Taylor reflected on their goals for student learning, including helping students become more scientifically literate and better thinkers, revealing their KoG as a component of their baseline PCK.
- Taylor shared their desire to develop skills through the MS program related to scientific communication and sharing ideas with other science educators.

- Taylor discussed the value of building mental resilience through the challenges posed by the MS program, including content, time management, and responsibility challenges.

Codebook 4

Codebook 4 then allowed me to break down the teacher statements by source of motivation. Each comment was assessed to determine the focus of the comment, either focused on the participant's learning, their students' learning, or the participant's teaching. Coding frequencies are displayed in Table 13.

Table 13. Initial Interview Coding Frequencies – CB4

Code	**Abbreviation**	**Frequency of Responses (*N* = 35)**	**Percentage of Total Responses (%)**
Learning-focused	L-f	9	25.7
Student-focused	S-f	10	28.6
Teaching-focused	T-f	16	45.7

Taylor's responses to the initial interview were mostly motivated by their teaching (45.7%). Their remaining comments were split between student-focused (28.6%) and learning-focused (25.7%) motivations. An example of each code is given below.

- "I genuinely think [the MS program is] going to help me become a more reflective, better teacher." (T-f)

- “I hope to gain a greater ability to create a passionate and welcoming and engaging environment that is dedicated to welcoming students in a way that inspires them to see the world through a different lens.” (S-f)
- “I definitely hope to gain a deeper understanding or a deeper comfort level with content.” (L-f)

Summary of Initial Interview

The initial interview followed up on Taylor’s responses to the initial survey and expanded on their goals for their time in the MS program. Taylor’s comments were motivated by their teaching (45.7%), their students’ learning (28.6%), and their own learning (25.7%). The main themes from the initial interview were:

- In the context of the MS program, Taylor expressed positive attitudes toward developing chemistry content knowledge, pedagogical and research skills, teaching confidence, and mental resilience.
- Taylor shared their goal for reigniting their passion and motivation for teaching that was negatively impacted by the COVID-19 pandemic.
- Taylor hoped to gain skills related to scientific communication and hoped to exchange ideas with other science educators participating in the MS program.
- Taylor described how improvements to their chemistry content knowledge (KoSc) would positively impact student learning (KoSt) and their teaching effectiveness (KoT). This combination of knowledge bases demonstrates the quality of Taylor’s baseline PCK.
- Taylor shared goals related to conducting research in their own classroom and spending time reflecting on their teaching practice. They described having a

research-based teaching approach and the MS program would allow them to evaluate changes in their teaching more effectively.

- The MS program would help Taylor become a more effective teacher, which would positively impact their students' learning. One of their main teaching motivations related to helping students become scientifically literate (KoG), a goal which would be supported through their development of skills and knowledge in the MS program.
- Taylor's initial interview demonstrated their desire to improve components of their PCK. Through combination of these knowledge bases, the Taylor demonstrated their potential to improve the quality of their overall PCK as well.

Teaching Observation – Baseline

Pre-Observation Survey

Upon scheduling the Zoom teaching observation, I sent the pre-observation survey to Taylor by email to complete prior to the observation. The pre-observation survey was coded using Codebooks 1, 2, and 4.

Codebook 1

Codebook 1 coding frequencies are shown in Table 14.

Table 14. Pre-Observation Survey Coding Frequencies for Baseline Observation – CB1

Code	**Abbreviation**	**Frequency of Responses (*N* = 7)**	**Percentage of Total Responses (%)**
Attitudes	A-c	2	28.6

Knowledge	K-p	1	14.3
	K-c	1	14.3
Skill	S-c	1	14.3
Teaching	T	3	42.9

In the pre-observation survey for the baseline observation, Taylor chose to teach "Intro to real vs. ideal gas behavior and using Van der Waal's equation to describe non-ideal gas behavior."

Attitudes (A-c)

Their current attitudes (A-c) about the lesson focused on confidence:

- "I feel fine about the lesson. I've taught this specific topic one time before, made some improvements, and feel fairly confident that they should be able to explain why some gases deviate from ideal behavior."
- "I think my confidence in the lesson stems from the fact that I really had to wrestle with the concept itself when first learning how to teach it."

Knowledge (K-p and K-c) and Skill (S-c)

Taylor's comment on prior knowledge focused on their initial understanding of the content (KoSc).

- "When I knew I was going to teach it a year or two ago, I didn't have a deep understanding."

They then discussed their work toward deeper content knowledge (KoSc) and how this informs their skill of identifying gaps in student knowledge (KoSc).

- "This forced me to really pin down the concept and address my own gaps in understanding, which helps me anticipate those very same gaps in my students."

Teaching (T)

Taylor's discussion of their lesson plan focused on their intentions for student learning (KoCO) and assessment methods (KoA) that will be used to inform future instruction.

- "I've added a phenomenon at the beginning of the lesson for students to think about and serve as an anchor point that can be referred back to throughout the lesson. Additionally, I've added an opportunity for formative assessment in order to gather immediate evidence to inform how I will proceed with the current and next lesson."

Their anticipation of student reactions to the lesson also touched on their teaching knowledge.

- "Real vs ideal behavior can be conceptually demanding for some. This can often lead to challenges throughout the lesson when trying to think about what exactly is going on and why. Additionally, even though I'm confident in their math skills, using the Van der Waal's equation can be difficult as well. Since this is an intro to the topic, I would anticipate them walking out of class with a basic conceptual awareness of the differences between real vs. ideal and the circumstances in which we need to consider deviations from ideal behavior."

Codebook 2

Codebook 2 coding frequencies can be found in Table 15.

Table 15. Pre-Observation Survey Coding Frequencies for Baseline Observation – CB2

Code	**Abbreviation**	**Frequency of Responses (*N* = 6)**	**Percentage of Total Responses (%)**
Knowledge of goals	KoG	1	16.7
Knowledge of students	KoSt	1	16.7
Knowledge of curriculum organization	KoCO	1	16.7
Knowledge of teaching	KoT	2	33.3
Knowledge of assessment	KoA	1	16.7

Taylor's comments on their lesson plan related to KoT, KoCO, and KoA. These comments overlap with the statements provided in the discussion of Codebook 1, so I will not restate them here. Their anticipation of student reactions related to both their KoSt and KoG.

Codebook 4

Codebook 4 was used to demonstrate the motivations behind the teacher's comments. These coding frequencies are shown in Table 16 below.

Table 16. Pre-Observation Survey Coding Frequencies for Baseline Observation – CB4

Code	**Abbreviation**	**Frequency of Responses (N = 12)**	**Percentage of Total Responses (%)**
Learning-focused	L-f	3	25
Student-focused	S-f	6	50
Teaching-focused	T-f	3	25

Taylor's comments in the pre-observation survey involved all three sources of motivation: learning-focused, student-focused, and teaching-focused. Half of their comments related to student learning, while the remaining comments were evenly split between learning-focused and teaching-focused motivations.

Summary of Pre-Observation Survey

Taylor's pre-observation survey contained five of the seven components of PCK and focused on their plan for the observed lesson. The main themes for the pre-observation survey were:

- Taylor felt confident in their ability to teach the behavior of real gases due to their own content knowledge and confidence in their pedagogical skill.
- Taylor described improving this lesson based on prior experiences and described their ability to anticipate gaps in student knowledge due to their own issues with the content. This reveals Taylor's desire and ability to make changes to better support student learning.

- Taylor embedded assessment methods in their lesson plan in order to "gather immediate evidence" for student understanding or confusion, demonstrating their KoA.
- Taylor expressed their KoSt by considering students' prior knowledge and anticipating challenges to student understanding. They demonstrated good quality PCK by creating a lesson using teaching and assessment strategies (KoT and KoA) that aligned with their KoSt.

Teaching Observation

All teaching observations were conducted via Zoom. Early in Taylor's first semester in the program, I conducted a baseline teaching observation to assess their current level of teaching effectiveness and active PCK prior to any program impact. During the observation, I took notes guided by the Instruction domain of the Danielson Framework for Teaching Evaluation Instrument.[62] The notes of the teaching observation were then analyzed using a subset of Codebook 2. Codebook 2 coding frequencies can be found in Table 17.

Table 17. Baseline Observation Coding Frequencies – CB2

Code	**Abbreviation**	**Frequency of Responses (*N* = 28)**	**Percentage of Total Responses (%)**
Knowledge of goals	KoG	5	17.9
Knowledge of curriculum	KoCO	1	3.6

organization			
Knowledge of teaching	KoT	11	39.3
Knowledge of assessment	KoA	10	35.7
Knowledge of resources	KoR	1	3.6

KoG

At the start of the lesson, Taylor communicated their expectations to students, including the learning objectives and what they want students to be able to explain after the lesson. They also explained the goal for the activity. Taylor also included real-world connections or analogies in their instruction.

KoCO

When beginning the lesson, Taylor explained the course schedule, tasks for the day, and what is coming up in the class, demonstrating their communication as well as their KoCO.

KoT

During the lesson, Taylor gave their students time to work together and discuss problems. They also communicated to their students that they were asking good questions, including asking students to pose the question to the full class to redirect the discussion. They asked students what they expected to see quantitatively and qualitatively related to a classroom demonstration. They utilized whiteboards during discussions and encouraged students to make observations during the demonstration. When working through a practice problem, they presented multiple approaches to finding the correct answer. The slides used to support instruction were clear and supported discussions in real time.

KoA

Taylor repeatedly checked for understanding and asked if students needed clarification throughout the lesson. They frequently used direct questioning during the lecture to assess student understanding. They asked students to explain their observations from the demonstration and checked for any remaining questions at the end of the lesson.

KoR

Taylor used liquid nitrogen for a classroom demonstration, demonstrating their KoR.

Post-Observation Survey

Once I was notified that the Zoom observation was complete, I sent Taylor the post-observation survey by email. The post-observation survey was coded using Codebooks 1, 2, and 4.

Codebook 1

Codebook 1 coding frequencies are shown in Table 18.

Table 18. Post-Observation Survey Coding Frequencies for Baseline Observation – CB1

Code	**Abbreviation**	**Frequency of Responses (*N* = 7)**	**Percentage of Total Responses (%)**
Attitudes	A-c	1	14.3
Teaching	T	4	57.1

Reflection	R	2	28.6

Attitudes (A-c)

Taylor reflected on their confidence that student learning took place during their lesson or real versus ideal gases (KoSt and KoA).

- "I'm confident that the majority of students learned to identify the circumstances in which gases deviate from ideal behavior as well as well as a basic understanding of why the deviation occurs at the particle level."

Teaching

In terms of teaching, Taylor discussed the teaching procedures for their lesson (KoT) and changes they would make in the future.

- "Much of my confidence [that student learning took place] simply comes from the consistency and accuracy of responses I heard throughout the lesson when questions were asked."
- "In the future, I think it would be better to give students time to try and explain why one of the balloons didn't shrink nearly as much as the other when placed in the liquid nitrogen. They likely won't be able to effectively, but it's important for them to recognize where gaps in understanding are."

They shared that the lesson went as expected "for the most part."

- "I took a bit longer during the intro phenomenon than I had wanted to. This delayed me a bit and I would've liked to spend a bit more time on the conceptual questions prior to attempting the quantitative Van der Waal question. Other than that, the type of informal evidence I gained throughout the lesson via questioning was as expected."

Taylor discussed whether they noticed any student confusion or misconceptions (KoSt).

- "There did not appear to be any noticeable misconceptions throughout the lesson. However, since this was an introduction to the topic, I'm confident confusion or misconceptions are present—I just needed to create more opportunities for them to be visible. The only real part of the lesson that suggested some kind of confusion was from the calculation they made with the Van der Waal's equation. Many of the answers they provided were near each other but lacked in consistency and some lacked in accuracy. This told me that, during the beginning of the next lesson, I want to walk through a problem like that with them and make sure they can confidently handle the algebra needed to solve the equation. Additionally, I want to ensure they understand what exactly their answer means in the context of real vs. ideal gases."

<u>Summary of Teaching</u>

Taylor discussed their teaching (KoT) when reflecting on their observed lesson. The main themes were:

- Taylor was confident that student learning took place during their lesson by assessing student understanding throughout the lesson. Although they did not notice any misconceptions, they stated that they may be present, which prompted them to incorporate more opportunities for informal assessment throughout their future lessons in the unit.

- Taylor reflected that their lesson mostly went as expected but explained their desire to manage time differently for this lesson in the future.

Reflection

Taylor shared that they would repeat their lesson and reflected on their KoT and KoCO.

- "I would definitely repeat the general flow of the lesson. I really liked starting with a phenomenon this time because it provided evidence that our current model of gas behavior needed to be modified."

Taylor also discussed changes they would make to allow for easier assessment of student misconceptions (KoA).

- "This was the part of the lesson I wish I would have created more explicit opportunities for reflection so that potential misconceptions could be drawn out more easily.

Codebook 2

Codebook 2 coding frequencies can be found in Table 19.

Table 19. Post-Observation Survey Coding Frequencies for Baseline Observation – CB2

Code	**Abbreviation**	**Frequency of Responses (N = 11)**	**Percentage of Total Responses (%)**
Knowledge of goals	KoG	2	18.2
Knowledge of students	KoSt	4	36.4

Knowledge of teaching	KoT	3	27.3
Knowledge of assessment	KoA	2	18.2

Taylor demonstrated their KoG by describing their goal for their students to understand the Van der Waal's equation "in the context of real vs. ideal gases."

Multiple comments focused on Taylor's KoT by describing the teaching procedures they focused on for their observed lesson. Taylor discussed their use of phenomena, questioning techniques, and practice problem calculations.

Most of Taylor's comments related to their KoSt by discussing student learning that took place, anticipating student thinking, identifying student confusion. They also shared their KoSt and KoA through their evaluation of whether students understood the content presented in the lesson.

- "Based on informal evidence collected throughout the lesson (verbal responses) and direct evidence from their calculation using the Van der Waal's equation, I would say that yes, I have good reason to think the majority of students understood what was talked about—at least enough to adequately dig deeper the next lesson."

They further discussed their KoA through "informal evidence…via questioning," demonstrating the formative assessments they conduct throughout the lesson to assess student understanding.

Codebook 4

Codebook 4 was used to demonstrate the motivations behind the teacher's comments. These coding frequencies are shown in Table 20 below.

Table 20. Post-Observation Survey Coding Frequencies for Baseline Observation – CB4

Code	Abbreviation	Frequency of Responses ($N = 9$)	Percentage of Total Responses (%)
Student-focused	S-f	4	44.4
Teaching-focused	T-f	5	55.6

Taylor's post-observation survey included reflections on their own teaching (55.6%) and their student's learning (44.4%).

Summary of Post-Observation Survey

The post-observation survey allowed Taylor to reflect on their observed lesson and determine what changes they may want to make in the future. The main themes for the post-observation survey were:

- Taylor was confident that learning took place due to "the consistency and accuracy of [student] responses" to Taylor's informal assessments throughout the lesson.
- Taylor described their desire to have students identify their own "gaps in understanding," demonstrating their KoG. They also wanted to "create more explicit opportunities for reflection" to draw out student misconceptions. Taylor displayed their ability to allow students to take part in the learning process.

Summary of Baseline Observation

Taylor's baseline observation took place at the beginning of the Fall 2021 semester and established a baseline for their teaching confidence and effectiveness. They taught a lesson over real versus ideal gas behavior, including the use of Van der Waal's equation. The main themes for the baseline observation were:

- Taylor described feeling confident in their teaching ability prior to the lesson and expressed confidence that learning took place.
- Taylor communicated the class schedule and expectations to their students, indicating KoCO.
- Taylor embedded informal assessments into their lesson to check for student understanding and was able to confirm that student learning took place due to this "informal evidence [they] gained throughout the lesson." This demonstrated their KoA, a component of their overall PCK. These planned assessments were confirmed during the observation.
- Taylor expressed their KoSt by accounting for students' prior knowledge in their lesson plan, as well as focusing on students' self-assessment of understanding and confusion. Taylor's inclusion of their students' needs demonstrates a combination of their KoG, KoT, and KoSt, an intertwining of knowledge bases that signifies PCK.

Taylor's baseline observation demonstrated their baseline PCK based on their KoG, KoSt, KoCO, KoT, and KoA. They have intertwined these knowledge bases, which indicates good quality PCK.

Summary of Baseline Data

To establish a baseline for Taylor's chemistry content knowledge, motivations for completing the MS program, and pedagogical skill, they completed the initial survey, content exam (pre-test), initial interview, and baseline teaching observation. The main themes from these data collection methods were:

- One of Taylor's primary goals for the MS program was to gain the content knowledge and skills necessary to helping students develop critical thinking and scientific literacy skills. They described their intention to become a more effective teacher through the MS program, which would in turn positively impact student learning.
- They also hoped for improvements to their research skills, teaching confidence, and mental resilience.
- Through the MS program, they intended to reignite their passion and motivation for teaching that was negatively impacted by the COVID-19 pandemic.
- Taylor was motivated to gain skills to be able to conduct research in their own classroom, a goal whose attainment would be aided by their completion of the action research project in the MS program.
- Taylor's baseline chemistry content knowledge was determined by their score to the pre-content exam, which was 29/50 (58%). This also demonstrated Taylor's baseline KoSc.
- The baseline observation indicated Taylor's baseline KoG, KoSt, KoCO, KoT, and KoA, which revealed their baseline PCK. They also exhibited their ability to

combine these bases, which revealed good quality PCK in addition to the basic presence of these knowledge bases.

Semester 1

During Semester 1, Taylor participated in two chemistry content courses. CHEM 770 focused on atomic theory and bonding. CHEM 771 focused on intermolecular interactions and phases of matter. These courses were fully online and primarily asynchronous. Optional weekly Zoom sessions were offered for each course and were the only synchronous components. The data for Semester 1 is presented chronologically. Taylor participated in their first progress teaching observation, along with pre- and post-observation surveys, near the end of the semester. The CoRe and Teaching Script assignments were both due near the end of the semester, along with module surveys. The End-of-Semester survey was sent out after the conclusion of the semester. Table 21 discusses the methods used during the Semester 1.

Table 21. Semester 1 Data Collection Methods

Term	**Data Collection Methods**	**ID Codes**
Semester 1	**CHEM 770:**	
	Discussion Forums	DF
	Teaching Script	TS
	Module Survey	MS
	CHEM 771:	
	CoRe	CoRe
	Module Survey	MS

	General: Teaching Observation End-of-Semester Survey	 TO EOS

Discussion Forums (CHEM 770)

In the Fall 2021 semester, discussion forum threads were introduced into the CHEM 770 courses three times throughout the semester to learn more about how this content course impacted participants. The discussion forum questions related to the impact of the course on the teaching of specific chemistry topics, what changes participants carried out (or planned to carry out) in their classrooms, and what new knowledge the teachers took away from the discussion forums in general. Specific questions can be found in Appendix J. Discussion forums were analyzed with Codebooks 1, 3, and 4. Codebook 3 data will be presented in Chapter 6.

Codebook 1

Codebook 1 provides general coding for the dataset. The codes and frequency of teacher responses can be found in Table 22.

Table 22. Discussion Forum Coding Frequencies for Semester 1 – CB1

Code	**Abbreviation**	**Frequency of Responses (N = 19)**	**Percentage of Total Responses (%)**
Attitudes	A-c	1	5.3
Knowledge	K-p	1	5.3

	K-c	5	26.3
Teaching	T	4	21.1
Feedback	F	1	5.3
Interaction	I	3	15.8
Reflection	R	4	21.1

Attitudes (A-c)

Upon reflection, Taylor shared the following attitude related to how the CHEM 770 course had impacted how they would teach quantum theory.

- "The whole development of quantum theory has been a fascinated story and I'd feel wrong if I didn't find more ways to share that story and understanding with my students."

The course inspired them to bring more quantum theory into their instruction. They demonstrated a combination of their KoSc and KoT, which reveals higher quality PCK.

Knowledge (K-p and K-c)

When discussing the impact of the CHEM 770 course on how they would introduce atomic theory topics to their students, Taylor reflected on their prior knowledge and how this knowledge has been transformed through their experience in the course.

- K-p: "Going into this course, I felt that I had a reasonable grasp of the evidence, experiments, and reasoning that led to one model replacing another throughout the development of atomic theory. I knew enough to teach it in a confident way that I was happy with."

- K-c: “However, so far this course has helped completely reshape everything I thought I knew about atomic theory. Each week seems to be filling some kind of gap in my understanding where I'm now able to understand the experiments and reasoning in ways I hadn't even thought of. The Planck topic really showed me how much more there was still to learn about this topic.”

Taylor expressed that, prior to the course, they were able to teach atomic theory with confidence, but the CHEM 770 course filled gaps in their knowledge that positively impacted their understanding and reasoning related to the topic. Thus, CHEM 770 positively impacted their KoSc and improved their PCK. Additionally, increased understanding (KoSc) would lead to improved teaching (KoT) for Taylor, thus demonstrating improved PCK quality.

- “Understanding the content at a deeper level is going to positively impact my teaching, regardless of the topic. The more I understand, the more connections and ideas I can make when considering how to teach atomic theory.”

Taylor then shared how the CHEM 770 course has impacted their knowledge of quantum theory topics (KoSc). Again, they discussed how their level of content knowledge (KoSc) impacts the level to which they can teach (KoSc), highlighting the quality of their PCK.

- “This class has helped me appreciate the importance these topics played in the birth and necessity of quantum theory…But once quantum ideas start playing more and more of a role in the subsequent models, the new evidence doesn't play as much of role in my current teaching. I'm pretty sure it was just because I didn't really understand it like I do now.”

Taylor’s final comments related to their current knowledge level after taking CHEM 770 focused on what they have taken away from the discussion forums to use in their future teaching. Connecting to their interactions with other teachers in the program, Taylor identified current gaps in their understanding that were being rectified by learning in community with other science teachers. Through these interactions, they further developed their KoSc as a component of their PCK.

- “However, sometimes there are little gaps in my understanding, or I still feel limited in the ways I think about a topic. Reading the various perspectives and interpretations on a given topic from people who are also learning this stuff along with me is really beneficial.”

They also elaborated on why the discussion forums had helped them develop a better understanding of CHEM 770 topics. By focusing on the “connections…between the concept, teaching, and resources,” Taylor expressed improvements to their PCK during their first semester in the MS program due to improved KoSc.

- “The discussion forums have actually helped improve my overall depth of understanding in ways I didn't really expect. Even for discussion questions that have limited answers (ex. "what is blackbody radiation"), since people aren't just going to state the same thing over and over, they end up approaching the question from different angles. This causes a large variation in connections made between the concept, teaching, and resources.”

Teaching (T)

Many of the discussion forum prompting questions related to how the CHEM 770 course has impacted teachers’ approaches to teaching atomic theory and bonding. The first two comments relate to how Taylor would teach quantum theory and atomic theory to their students after participating in this course. These comments demonstrate Taylor's KoSt and KoT, therefore revealing improvement to the quality of their PCK.

- "After discussing the problems with Rutherford's model, I usually jump right into Bohr. However, I want to allocate time for wave-particle duality, photoelectric effect, and Planck's constant…The whole development of quantum theory has been a fascinated story and I'd feel wrong if I didn't find more ways to share that story and understanding with my students."
- "By helping me fill the gaps in my own understanding, it's helping me think about how to reconstruct my process for this unit. Additionally, it's going to help me talk about this stuff when kids have questions, since I'll be able to approach it from more angles. The first thought that came to mind is how I might use this to improve my Honors Chem class. There isn't really much of a difference in atomic theory between Gen Chem vs. Honors Chem. However, I'd love to have the opportunity with my Honors kids to dig deeper and get into topics such as blackbody radiation, Planck's role, Franck-Hertz experiment, and Einstein. This type of stuff is something that will challenge them, but I know they're capable of handling it. Building a more logical progression by getting into a greater level of detail, while still being developmentally appropriate, is part of what justifies an upper level course anyways. Overall, this course is helping me see this topic in ways I hadn't thought much about. When we eventually get to our atomic theory unit, I'm confident that Planck and the early drummings [sic] of quantum theory will find its way into my unit."

- “I plan to place a much greater emphasis on the role of light throughout the development of the atom. For example, I have never included anything regarding blackbody radiation and its connection to the development of the idea that energy is quantized, which inevitably led to the idea of matter being quantized. Considering we talk about quantum models and ideas, it seems only appropriate to give attention to such topics in order to provide sufficient evidence for supporting the replacement of one atomic model over another.”

Taylor’s comments above related to how they planned to bring new content from the CHEM 770 course into their classroom, which combines their KoSc and KoT and indicates improved quality of their PCK. The following comment related to bringing in new activities or refreshing activities they had already used in the past.

- “Since Spring of 2020, I've gotten so swept up in logistics and just ‘making things work’ that I've neglected some of the stuff I used to do. Now that we're back in person, I'm hoping many of these past activities, as well as new ones I learn from [discussion forums], will find a way back into my curriculum.”

Feedback (F)

Taylor shared one comment coded as feedback. This statement was further analyzed using Codebook 3, which will be shared in the section below.

Interaction (I)

The following discussion forum comments include responses to other MS program participants, demonstrating Taylor’s interactions with other teachers, as well as comments on the importance of these interactions. The discussion forums allowed Taylor to gain new content and pedagogical knowledge, in addition to forming new connections with a geographically diverse group of educators.

- "Your point about 'clarification of complex concepts and consolidation of some aspects of my content knowledge' was very relatable to my own interactions with these discussions forums…Reading the various perspectives and interpretations on a given topic from people who are also learning this stuff along with me is really beneficial."
- "It's really nice to get a group of like-minded people discussing similar topics while still having a diversity of thoughts."

The following comment combines a response to a teacher's use of POGIL and Taylor's comments on the similarities between this approach and an activity they had used in their own classroom. Their interaction in this discussion forum demonstrates improvements to the quality of their PCK through their development of their KoR, KoCO, and KoSt.

- "Though I've been aware of POGIL for several years, I don't really know the details behind it and what exactly students are doing…I've been using something similar in my Chemistry Concepts class this year in an effort to incorporate more of the NGSS-type material into the curriculum…Cool idea!"

These discussion forum posts reveal Taylor's approach to participating in discussions and interacting with their fellow teachers, which included a high level of engagement.

<u>Reflection (R)</u>

Some of Taylor's discussion forum posts included elements of self-reflection. Taylor reflected on connections they made to their past teaching, the development they have experienced through the CHEM 770 course, and their intentions for student learning.

- “I've had the same feeling multiple times throughout the past couple of weeks. I'll be reading someone's post and then all of a sudden I'm like, "wait, that reminds me of "X" thing I did in the past!’”
- “Being exposed to [fellow teachers’ posts to the discussion forums] makes your own brain start to work and I've noticed myself thinking about new ideas in ways I hadn't previously.”
- “Though we didn't get rid of the equations, the way in which we utilized the equations was very ‘surface-level’ and I felt it didn't really add much…I don't want to only focus on things such as calculating things like wavelength, frequency, and energy. I also want them to be able to make such calculations AND make inferences from those results as they relate to atomic structure.”
- “When I do an activity like this and explicitly provide kids with opportunities to work together first prior to talking about it as a whole class, I've noticed that there's a lot less engagement and it ends up just being me constantly asking questions with little participation.”

These statements reveal Taylor’s goals for improving their teaching and learning about new content and teaching strategies that they can bring into their future instruction. They expressed their desire to improve their KoSc and KoT as components of their PCK.

Codebook 3

Taylor shared one comment coded as “Feedback.” This statement was further analyzed using Codebook 3. These coding frequencies are shown in Table 23 below.

Table 23. Discussion Forum Coding Frequencies for Semester 1 – CB3

Code	**Abbreviation**	**Frequency of Responses (N = 1)**	**Percentage of Total Responses (%)**
Course Feedback	CF	1	100

Course Feedback

Taylor discussed the impact of the course materials on their conceptual understanding of CHEM 770 topics.

- "Much of how I initially formulate a conceptual framework for a given topic in this class comes from a combination of the book and Instructor A's videos."

Codebook 4

Codebook 4 was used to identify the source of motivation that fueled Taylor's comments. Coding frequencies can be found in Table 24.

Table 24. Discussion Forum Coding Frequencies for Semester 1 – CB4

Code	**Abbreviation**	**Frequency of Responses (N = 19)**	**Percentage of Total Responses (%)**
Learning-focused	L-f	6	31.6
Student-focused	S-f	3	15.8

Teaching-focused	T-f	10	52.6

The statements provided above from Taylor's discussion forum posts were mostly focused on their own teaching (52.6%) and learning (31.6%). Three comments focused on Taylor's student-focused motivations. Examples are given below for each code.

- "Since Spring of 2020, I've gotten so swept up in logistics and just 'making things work' that I've neglected some of the stuff I used to do. Now that we're back in person, I'm hoping many of these past activities, as well as new ones I learn from here, will find a way back into my curriculum." (T-f)
- "So far this course has helped completely reshape everything I thought I knew about atomic theory. Each week seems to be filling some kind of gap in my understanding where I'm now able to understand the experiments and reasoning in ways I hadn't even thought of." (L-f)
- "However, I'd love to have the opportunity with my Honors kids to dig deeper and get into topics such as blackbody radiation, Planck's role, Franck-Hertz experiment, and Einstein. This type of stuff is something that will challenge them, but I know they're capable of handling it." (S-f)

<u>Summary of Discussion Forums (CHEM 770)</u>

Most of Taylor's posts to the discussion forums focused on their current knowledge, teaching, and reflections on their experience in the CHEM 770 course. The course inspired them to bring atomic theory and bonding topics into their classroom. Taylor's comments were primarily motivated by their teaching and learning, but they also considered how their experience in the CHEM 770 course may impact student learning. The main themes of Taylor's comments were:

- The discussion forum allowed Taylor to reflect on their current teaching methods and reconsider how they would teach atomic theory and bonding topics in the future in light of what they learned in the CHEM 770 course.
- Taylor demonstrated a combination of knowledge bases in their discussion forum posts, including all seven components of PCK. This demonstrates Taylor's baseline of PCK, showing that it would be necessary to observe changes in the quality of their PCK.
- Taylor was aware of how increased chemistry content knowledge (KoSc) would positively impact their future teaching of these topics (KoT), highlighting the baseline quality of their PCK.

CoRe

In Fall 2021, the CoRe was administered in CHEM 771: Intermolecular Interactions & Phases of Matter. The CoRe was analyzed using Codebook 2 to assess participants' PCK. Table 25 displays the codes from Codebook 2 that appeared in Taylor's Semester 1 CoRe.

Table 25. CoRe Coding Frequencies for Semester 1 – CB2

Code	**Abbreviation**	**Frequency of Responses (*N* = 36)**	**Percentage of Total Responses (%)**

Knowledge of science	KoSc	17	47.2
Knowledge of goals	KoG	1	2.8
Knowledge of students	KoSt	5	13.9
Knowledge of curriculum organization	KoCO	2	5.6
Knowledge of teaching	KoT	4	11.1
Knowledge of assessment	KoA	6	16.7
Knowledge of resources	KoR	1	2.8

KoSc

The first component of PCK represented in the CoRe is KoSc, which includes science content, scientific practice, the nature of science, and scientific progress.[41] In the CoRe assignment, participants discussed a challenging topic related to intermolecular interactions and phases of matter that they would like to teach. Almost half (48.6%) of Taylor's statements in the CoRe related to KoSc. Taylor chose to create a CoRe about "the relationship between structure/IMFs and properties of substances." Taylor then explained why this topic is challenging for them. The challenging nature of the topic was focused on identifying student misconceptions, which connects to their KoSt and KoA as components of their PCK.

- "I considered this topic to be most challenging because it relies upon several previous ideas, each of which is rather conceptual, to have already been

> understood in order to explain any differences in properties between substances. As a result, navigating this topic with many students can be difficult since it can be hard to pin down exactly where the misconception is that leads to an incorrect answer. The relationship between structure and properties is a cumulative idea and this means more ways for students to misunderstand or misinterpret ideas along the way that serve as an obstacle to effectively teaching this relationship."

When identifying intentions for student learning, Taylor listed student learning outcomes related to bond polarity, molecular polarity, "infer[ring] which intermolecular forces are present," and to "explain, predict, and differentiate properties of difference substances based on IMFs." These intended learning outcomes connected to their KoCO. Taylor then shared their additional knowledge on this topic, which related to additional properties and more complex examples than they would teach their students. Taylor then listed difficulties or limitations associated with teaching their chosen topic. Many of the difficulties relate to students' prior knowledge (KoSt). Some examples are listed below.

- "Reliance on competency in determining molecular structure, which will vary widely among students."
- "Lack of background in physics can make it difficult to understand and discuss the topic of forces and how these electrical interactions impact behavior of particles."
- "Lack of background knowledge with vectors can make it difficult to evaluate the net dipole of a molecule."

Other examples of difficulties or limitations related to the content itself (KoSc).

- “Dealing with anomalies in properties based on what we have learned (ex: BP of $SiBr_4$ and CBr_4).”
- “Interpreting macroscopic observations based on particle-level interactions.”

Taylor demonstrated their KoSc by describing their chosen topic, including additional content knowledge, as well as identifying complexities of the topic. Taylor combined their KoSc with their KoSt, particularly in relation to their students’ prior knowledge, which demonstrated improved PCK quality.

Summary of KoSc

Taylor demonstrated their KoSc by discussing the relationship between substances’ structure and properties, including intermolecular forces. They shared additional knowledge of these topics and discussed their intentions for student learning, which combined their KoSc and KoCO, demonstrating higher quality PCK. When discussing student misconceptions, they demonstrated higher quality PCK by combining their KoSc and KoSt.

KoG

The next code for the CoRe assignment relates to KoG, which may include learning goals for scientific literacy, real-life application, and integrated understanding.[41] This code specifically aligned with the prompting question for the importance of learning the concept. Taylor shared their opinion of a main goal for learning chemistry, which related to applying particulate level understanding to the world around us.

- “One of the primary goals of learning chemistry is to understand the macroscopic world based on what’s occurring at the particle level. Connecting these two ‘worlds’ is especially important when attempting to account for the differences in properties between various substances. Students are constantly interacting with substances and therefore, the properties of these substances…The application of this knowledge can allow for better decisions to be made when deciding which substance to use for a specific task…The better we understand what is taking place at the particle level to account for such properties, the more likely we can use it to our advantage to utilize and create things to make our lives better."

KoSt

The next code is KoSt, which may focus on different learning levels, needs, interests, prior knowledge, ability, learning difficulties, and misconceptions.[41] Taylor shared the intended student learning context for teaching this specific lesson. They explained that "the class that [they] would teach this concept with any sufficient detail is Honors Chemistry."

Taylor also shared general knowledge about their students' thinking. Their KoSt informed their decisions about how they plan to teach this concept, which combined their KoSt and KoCO and demonstrated higher quality PCK.

- "In general, students struggle with developing a particle-level understanding of phenomena. Since properties are the result of particle-level interactions, it will be important that I place a firm emphasis on the particle level understanding, while still providing space for symbolic and macroscopic levels of understanding."
- "It will be difficult for them to visualize the 3D aspects related to VSEPR. As often as possible, find ways to incorporate actual visuals or tangible models that can be manipulated to reflect changes in geometry."

- “Students tend toward algorithmic thinking. Many will search for the path of least resistance, even at the expense of understanding. With several prerequisite concepts building to an explanation of properties, be mindful of this tendency and create opportunities for them to avoid being over reliant on just memorizing things such as types of IMFs.”
- “Students crave for simple rules and often hide behind memorized terms to disguise understanding. Don’t fall into trap of simply memorizing different types of IMFs and letting that pass as understanding.”

Summary of KoSt

Taylor demonstrated their KoSt by detailing common student struggles with content, methods for supporting student learning, and typical student behavior during learning. Taylor incorporated their KoSt into their KoT, which demonstrated improvements to the quality of their PCK.

KoCO

The next code relates to KoCO, which may relate to state and local standards.[41] In the CoRe assignment, teachers were asked to name the standards that are relevant to their chosen topic. Taylor chose to include a state standard that is most relevant to their chosen topic:

- “Plan and conduct an investigation to gather evidence to compare the structure of substances and infer the strength of electrical forces between particles.”

<u>KoT</u>

The next code is KoT, which involves the discussion of teaching methods and activities.[41] First, teachers were asked to share the teaching procedures related to their chosen lesson. Taylor discussed their plan for teaching in great detail.

- "Think-Pair-Share: Ask students to describe what it means for one substance to have a higher BP than another in terms of attraction between particles within each substance. Many students recognize a higher BP means more energy was required to make it boil. However, far fewer students can make the appropriate inference about energy needed and strength of attractions. They almost see differences in energy needed as an inherent property rather than the result of differences in strength of attractions between particles. On this same topic, I could easily flip the script and give them types of forces that are present within a substance and ask them to rank and defend the MP/BP of each substance. This would help emphasize this relationship between particle interactions and energy."
- "Incorporate the PhET simulation related to molecular geometry as a way to introduce the concept and more easily visualize differences in geometry[71]. Students may not immediately understand how the shape of a molecule can be altered by the presence of a lone pair of electrons. By having the ability to add/remove bonds and/or lone pairs, this will help them see how such things impact structure."
- "To help avoid an overreliance on algorithmic thinking while accounting for differences in properties, think about helping them develop a set of 'approach questions' they need to ask themselves that can be consistently applied. These approach questions may help break down a problem into its components and make

conceptual problems more attainable for some students. Though scripting this approach may be algorithmic, each step throughout the script still relies on a conceptual understanding. Chunking the concept into questions that lead to the answer may benefit students experiencing cognitive overload and struggle with not knowing where to start."

After discussing their teaching procedures, the participants were asked to share the factors that influence their teaching. Taylor combined their KoT with their KoSt by discussing how student thinking influences their instruction, which demonstrates higher quality PCK.

- "Providing data that displays differences in properties has its place, but it may be tough for some students make appropriate inferences solely from data. Try to incorporate demos and/or experiences for students to interact with these differences in properties. Giving them an experience to relate to may make it easier for them to account for such differences."

Summary of KoT

Taylor described their teaching procedures for their CoRe lesson, including a think-pair-share activity, a PhET simulation, and implementing a scripted approach for problem solving.[71] They also discussed the impact of student understanding on their teaching choices by describing the need for data interpretation support and demonstrations. They demonstrated their KoT, KoR, and KoSt, which showed improvement to the overall quality of their PCK.

KoA

The next code is KoA, which details teachers' knowledge of formal and informal assessments and feedback.[41] Taylor shared assessment methods in their explanation of teaching procedures for this lesson. By focusing on revealing student misconceptions, Taylor also revealed their KoSt. By combining their KoA and KoSt, Taylor demonstrated improvements to the quality of their overall PCK.

- "Due to the reliance on prerequisite skills and knowledge for this topic, it's essential that I provide frequent (low-stakes) assessments throughout to catch misconceptions early on before they become a problem down the road."
- "When providing opportunities for assessment, don't silo yourself into using only pencil-and-paper assessments. Think about how to incorporate more authentic assessments that bring out conceptual understanding. Attaching experiences to concepts may help deepen the ways students think about the properties they observe."
- "Feedback will be essential here. There are so many holes students may step in on their path to explaining properties. In addition to providing feedback on assessments, share common misconceptions with students and display examples of faulty reasoning for us to discuss. To avoid these holes, knowing what kind of holes to lookout for will be beneficial."

Taylor also included methods they would use to assess student understanding or confusion.

- "Whiteboarding their ideas will naturally bring out misconceptions such as '*this molecule is polar because it contains polar bonds*' or responses that don't account for the cumulative effect of certain interactions such as LDFs."
- "Find appropriate times to expose students to anomalies in properties (ex: BP of $SiBr_4$ and CBr_4). Asking students to explain anomalies can make it clear where a misconception is at and to what extent. This can help expose overreliance on algorithmic thinking or a lack of connection between concepts."
- "At various times, present students with numerous opportunities to evaluate the polarity of a molecular that happens to contain polar bonds but it still nonpolar overall. Students are quick to associate polar bond = polar molecule. Exposing this misconception several times can reduce its frequency over time."

Summary of KoA

Taylor demonstrated their KoA by outlining their approach to assessing student understanding, as well as their philosophy behind assessment. Taylor implemented assessments in order to expose student misconceptions. They also discussed the importance of sharing common misconceptions with students, which connects to their KoG. By combining their KoG and KoSt, Taylor demonstrated improvements to their PCK quality. Taylor allowed for students' active participation in the learning process and described the importance of feedback. Taylor combined their KoA and KoSt, which demonstrated improvements to the quality of their PCK.

KoR

The final code in Codebook 2 relates to KoR, which discusses materials and activities that teachers utilize in their classrooms.[41] Taylor identified PhET simulations as a resource they would use in their teaching.[71]

Summary of CoRe Data

Taylor structured their CoRe as a detailed plan that could be carried out in the future, including rationale for their teaching choices. Their CoRe demonstrated possession of all seven components of PCK, which suggests the presence of Taylor's PCK. Taylor also combined multiple knowledge bases throughout their CoRe, which demonstrated improvements to the quality of their overall PCK. The main themes for their Semester 1 CoRe were:

- Taylor gave extensive detail when describing their content knowledge and related the content to their teaching context by identifying aspects of the content that could potentially challenge students. This shows a combination of their KoSc, KoT, and KoSt, which demonstrates improvement to the quality of their PCK.
- Taylor included a variety of teaching methods in their lesson, which allowed for alternative methods depending on student reactions to the material. They also included multiple assessment methods, detailing the importance of frequent "low-stakes" assessments and feedback. Taylor's assessment methods focused greatly on identifying misconceptions and making students aware of possible misconceptions before they occur. Their KoT and KoA both reflected their KoSt, demonstrating the combination of PCK bases used to create their CoRe lesson.

This combination of knowledge bases demonstrates improvement to their overall PCK.

- Taylor's CoRe was well-organized and detailed. Their teaching philosophy and goals for the lesson shone through the entire CoRe by demonstrating a deep understanding of each component of the module. Taylor provided specific reasoning behind their teaching choices, including what, how, and why they are teaching their chosen topic.

Module Survey – CoRe

After completing the CoRe assignment, teachers were invited to complete a survey about their experience creating a CoRe for their topic. The CoRe module survey was coded using Codebooks 1 and 4.

Codebook 1

Coding frequencies for Codebook 1 can be found in Table 26.

Table 26. Module Survey Coding Frequencies for Semester 1 CoRe – CB1

Code	**Abbreviation**	**Frequency of Responses (*N* = 12)**	**Percentage of Total Responses (%)**
Attitudes	A-c	2	16.7
Knowledge	K-c	4	33.3
Skill	S-c	1	8.3
Teaching	T	4	33.3
Modules	M	1	8.3

Reflection	R	1	8.3

For their chosen topic, Taylor would feel comfortable teaching without preparing beforehand but did not think it was a good teaching practice to do so. This demonstrates the impact of Taylor's teaching philosophy on their instructional choices.

- "Especially after learning more about IMFs and properties in this class (771), I'm confident enough in my content knowledge that I could create a sufficient narrative with students to help navigate this topic. I wouldn't feel good about it because I know much of the thinking and sensemaking would likely be dominated by me rather than students."

Upon creating a CoRe for their topic, Taylor found the module assignment to be "intellectually challenging and worthwhile" to take "the time to slow down, reflect on the topic, and genuinely think about things such as potential misconceptions and methods for helping students avoid such misconceptions." This demonstrates a combination of their KoSt and KoT, which reveals higher quality PCK.

When asked about their confidence level on a scale of 1 to 6 for teaching their concept, Taylor responded with a score of 5. Potential ways to improve Taylor's teaching confidence related to their KoR and KoSc, demonstrating that improved PCK would positively impact their confidence.

- "Awareness of more demos and possible lab experiences that elicit student thinking about the relationship between structure/IMFs and properties."
- "Increasing my own exposure to anomalies in properties to ensure I can account for them based on my own knowledge of this topic."

The content of the CHEM 771 course impacted Taylor's knowledge and skill (KoSc), which highlights improvements to their overall PCK.

- "It's helped me go beyond the simplistic routine of determining polarity of molecule, identifying forces present, and inferring certain properties. While all these things are still necessary, the content within this course has deepened my understanding of how electron arrangement impacts structure and what effect bulk-scale forces can have on properties."

The course content also impacted Taylor in terms of teaching. This improvement to their KoT demonstrates an improvement to their PCK.

- "It's also given me a greater awareness for how to tackle potential misconceptions by introducing me to anomalies in properties that can be accounted for."

The CoRe module also transformed Taylor's teaching of their chosen concept in terms of attitudes and knowledge. Their improved KoSc led to improved PCK.

- "Increased confidence with teaching LDFs."
- "Increase in exposure to anomalies in properties."
- "Greater consideration of how bonded and lone pair electrons affect shape of molecule instead of relying too much on a typical molecular geometry 'cheat sheet'."

Codebook 4

Codebook 4 was used to identify the source of motivation that fueled Taylor's comments. Coding frequencies can be found in Table 27.

Table 27. Module Survey Coding Frequencies for Semester 1 CoRe – CB4

Code	**Abbreviation**	**Frequency of Responses ($N = 7$)**	**Percentage of Total Responses (%)**
Learning-focused	L-f	3	42.9
Student-focused	S-f	3	42.9
Teaching-focused	T-f	1	14.3

The statements provided above from Taylor's CoRe survey were mostly focused on their own learning (42.9%) and their students' learning (42.9%). One comment focused on Taylor's teaching motivations. Examples are given below for each code.

- "Increasing my own exposure to anomalies in properties to ensure I can account for them based on my own knowledge of this topic." (L-f)
- "Increased confidence with teaching LDFs." (T-f)
- "Genuinely think[ing] about things such as potential misconceptions and methods for helping students avoid such misconceptions was intellectually challenging and worthwhile." (S-f)

Summary of Module Survey – CoRe

In the CoRe module survey, Taylor reflected on their experience creating a CoRe for a CHEM 771 topic. The main themes for their CoRe module survey were:

- Taylor expressed confidence in their content knowledge (KoSc) and shared their perspectives on good teaching practices.

- The CoRe gave Taylor an opportunity to reflect on the topic and think through potential student misconceptions (KoSt). They stated that their teaching confidence would increase with deeper content knowledge (KoSc) and a greater awareness of resources related to their chosen topic, such as labs and demonstrations (KoR). This reveals that improvements to their KoSt, KoSc, and KoR would positively impact their overall PCK quality.
- Taylor indicated that the CHEM 771 course strengthened their content knowledge (KoSc) and introduced them to knowledge that will help them address future student misconceptions (KoT). These improvements to their KoSc and KoT improved the overall quality of their PCK. The CoRe itself also helped Taylor become more confident with and knowledgeable on intermolecular interactions topics.

Most of Taylor's comments (85.7%) were motivated by their own learning and their students' learning. One statement was motivated by Taylor's teaching. These statements demonstrate Taylor's focus on gaining knowledge in the MS program for their own educational benefit as well as to benefit their students.

Teaching Script

In Fall 2021, the Teaching Script was administered in CHEM 770: Atomic Theory & Bonding. The Teaching Script was analyzed using Codebook 2 to assess participants' PCK. Table 28 displays the codes from Codebook 2 that appeared in Taylor's Semester 1 Teaching Script.

Table 28. Teaching Script Coding Frequencies for Semester 1 – CB2

Code	**Abbreviation**	**Frequency of Responses (*N* = 32)**	**Percentage of Total Responses (%)**
Knowledge of science	KoSc	6	18.8
Knowledge of goals	KoG	3	9.4
Knowledge of students	KoSt	7	21.9
Knowledge of curriculum organization	KoCO	4	12.5
Knowledge of teaching	KoT	6	18.8
Knowledge of assessment	KoA	0	0
Knowledge of resources	KoR	5	15.6

In addition to completing the table with prompting questions for the Teaching Script assignment, Taylor also included a document with their Teaching Script describing the background and purpose of their lesson. They also included rationale for their instructional choices throughout the script.

KoSc

The first component of PCK represented in the Teaching Script is KoSc, which includes science content, scientific practice, the nature of science, and scientific progress.[41] Taylor first described their topic choice, involving their KoSc as well as their KoCO, KoSt, and KoT. This combination of knowledge bases demonstrates higher quality PCK.

- "I chose de Broglie's application of wave-particle duality to matter as my topic because of the clarity it could bring to unanswered questions in my classroom regarding the Bohr model. It's a topic that I have been aware of since I started teaching but never truly took the time to understand its role within atomic theory. Additionally, the level of abstraction involved with this concept brings its own set of unique challenges when trying to teach it to high school students.

Taylor then demonstrated their prior knowledge on the topic of wave-particle duality, which revealed increases to their KoSc as a component of their PCK due to their engagement in the CHEM 770 course.

- "Waves can exhibit particle behavior and vice versa; this is the basis for wave-particle duality. To explain the photoelectric effect, Einstein realized that light waves can also behave like particles (photons). Einstein's quantization of light built off Planck's quantization of energy. de Broglie jumped off Einstein's idea and applied the same rationale to electrons when he claimed that particles can exhibit wavelike behavior. de Broglie envisioned the electron as a standing wave that is in phase with itself as it orbits the nucleus. Since the electron is in phase with itself, there is no apparent circular motion as it orbits the nucleus; this is why is doesn't lose energy and crash into the nucleus. Only certain wavelengths are allowed as a standing wave, which can account for why the electron remains in these quantized energy levels. de Broglie described matter waves mathematically as $E = \frac{hc}{\lambda}$."

Taylor then discussed the additional content knowledge they had on the topic above what they would involve in their instruction.

- "Mathematical description and calculations surrounding de Broglie's matter waves. This could be used to calculate matter waves of both big and small objects to understand why we don't see matter waves at our level. How experimental evidence from diffraction experiments confirmed the existence of matter waves."
- "To supplement for those wanting to know more or dive a bit deeper into de Broglie's idea, I would likely introduce them to de Broglie's wave equation and have them calculate that matter waves of both large and small scale objects to gain a sense of why we don't see these waves at the macro level. Additionally, I might provide some information on the diffraction experiments that confirmed the existence of matter waves."

In addition to the Teaching Script table, Taylor provided background information on their lesson. The following statements demonstrate Taylor's KoSc in conjunction with their KoT, which demonstrates higher quality PCK. Taylor was able to describe changes to their chemistry content knowledge (KoSc), as well as how they plan to bring this new content into their teaching (KoT).

- "Up to this point, well-known experiments such as Thomson's cathode ray and Rutherford's gold foil have provided us with plenty evidence to justify the development of a new model of the atom. However, when we get to Bohr's model, even though we use emission spectra to support Bohr's idea that electrons occupy only discrete energy levels, I completely bypass the fact that Bohr himself had no actual explanation for how electrons could exist in this quantized state.

- "I'm fairly confident that one of the primary reasons I have chosen to largely bypass digging into these questions is simply because I didn't have a complete understanding of how to answer them myself. Though I wouldn't say my current understanding is rock solid, it's certainly better than it was. This has given me confidence to want to attempt integrating de Broglie's ideas into my unit in an effort to answer these questions."

Summary of KoSc

- Taylor developed chemistry content knowledge in the CHEM 770 course that they planned to bring into their instruction. This combination of KoSc and KoT indicates improvements to the quality of their overall PCK.
- Taylor described the level of KoSc they brought into their classroom in the past versus how they plan to teach de Broglie's concepts in light of new content knowledge, again demonstrating KoSc and KoT, as well as KoCO. This combination of knowledge bases indicates improvements to their overall PCK quality.
- Taylor was able to detail their KoSc in depth, revealing the knowledge they had gained in the CHEM 770 course. These improvements to their KoSc demonstrated increased PCK.

KoG

The next code for the Teaching Script assignment relates to KoG, which may include learning goals for scientific literacy, real-life application, and integrated understanding.[41] Taylor first shared the importance of teaching de Broglie's concepts in their classroom, connecting to their KoCO. This combination of knowledge bases demonstrates higher quality PCK.

- "It's important because it reflects the theme of the unit, which is to rely upon solid evidence/theory to reasonably justify the characteristics of a new model of the atom."

They then described the purpose behind their lesson, including providing their students with foundational knowledge and scientific skills. This combination of their KoG and KoSt demonstrates higher quality PCK.

- "Ultimately, the driving force behind me wanting to do this is to remain consistent with the philosophy practiced throughout the unit, which is to demonstrate how evidence, theory, and experimental results fueled the development of atomic models. Since my current treatment of Bohr's model basically asks students to just accept this idea of electrons being in quantized energy levels where they happen to not emit energy as they orbit, this really rubs me the wrong way and I want to change that."
- "The goal here is to at least establish the idea of wave-particle duality so that by [the time] they hear about de Broglie's idea, it's not so foreign to them."

<u>Summary of KoG</u>

Taylor demonstrated their KoG through the inclusion of the following themes:

- Taylor described the importance of their atomic model unit, showing both their KoG and KoCO, which demonstrated improvements to the quality of their overall PCK.

- Taylor detailed the primary skills and foundational knowledge they aim for their students to gain through this lesson, illustrating improvements to the quality of Taylor's PCK through their intertwining of their KoG, KoSc, and KoSt.

KoSt

The next code is KoSt, which may focus on different learning levels, needs, interests, prior knowledge, ability, learning difficulties, and misconceptions.[41] Taylor first described the intended teaching context for their lesson by describing the group of students that would best receive the content.

- "While my current treatment of Bohr's model and the quantum ideas that follow may suffice for my general chemistry students, I feel like this is a topic I can explore more deeply with my Honors Chemistry students, which is primarily juniors. As a result, this would be my primary target set of learners. This is largely due to the level of abstraction behind wave-particle duality and its eventual application for how it supports the idea of the electron remaining in quantized energy levels without emitting radiation."

Taylor also described their KoSt through past experiences of their reactions to their atomic theory unit. They then explained their goals to support student learning (KoG). This combination of KoSt and KoG demonstrated improvements to the quality of their overall PCK.

- "Throughout the unit, my students have solid evidence for why one model was able to replace another. However, once we arrive at Bohr's model, it seems like I'm asking them to accept the idea of electrons existing within quantized energy levels as if it was a matter of faith. This goes against the philosophy of the whole unit and I think it could really help their understanding if I incorporate this concept."

When outlining the lesson, Taylor shared their students' level of prior knowledge of their chosen topic.

- "My students are capable of explaining how Bohr's model is an improvement from Rutherford's, but they lack any conceptual framework for how this model can even be plausible in the first place. They know the what, but they don't know the why."

Relying on past experiences, Taylor shared their KoSt by identifying potential misconceptions students may have during the lesson.

- "One misconception that I would anticipate is associated any form of wave as a standing wave."
- "Another misconception I would anticipate revolves around not making the connection between only specific electron wavelengths being available and the quantization of energy levels."

Similarly, Taylor also described student reactions to the content, including potential questions and behaviors.

- "Some of the primary follow-up questions I would anticipate would be: If all particles have wavelike features, why don't we see these waves on a daily basis? How do we know these matter waves actually exist? Even if an electron behaves like a wave, how exactly does that mean it won't emit energy as it orbits the electron? If the electron is a wave, does it actually orbit the nucleus in the same way the moon orbits Earth?"

- "I expect the majority of students to taken back by some of these claims simply due to the weirdness of the idea. In my experience, whenever discussing some of these abstract quantum ideas, the interest of many students is increased and a series of 'rabbit-hole-like' questions begin to arise."

Summary of KoSt

Taylor included many details of their own students when planning a lesson on CHEM 770 topics. The main themes for KoSt were:

- When designing a lesson for their atomic theory unit, Taylor took their students' prior knowledge and behaviors into account based on previous teaching experiences. Taylor incorporated their KoSt into their lesson plan.
- Taylor described their goals for student learning, taking into account both their KoSt and KoG, which revealed improvements to the quality of their PCK.
- Taylor's KoSt enabled them to apply new chemistry content knowledge to a lesson that would best suit their students learning. By combining their KoSt, KoSc, KoG, and KoT, Taylor demonstrated improvements to the quality of their PCK.

KoCO

The next code relates to KoCO, which may relate to state and local standards.[41] Taylor first described how their chosen concept fits into their existing atomic theory unit, exemplifying how they make decisions about what to teach.

- "This concept ties in perfectly with the theme of using supporting evidence/theory to justify the development of a new model of the atom. Instead of just accepting Bohr's idea of quantized energy levels out of faith, tying in de Broglie's wave treatment of electrons would supplement the rationale for Bohr's claim about quantized energy levels."

Taylor also described the lack of a relevant unit in their state and instead provided their own intended student learning outcome for the lesson.

- "Since the photoelectric effect is a physics-specific state standard, this is not a concept we will be diving into as much as I would personally like…Instead, I want my students to have enough familiarity with it to be able to see how it supports the idea of quantized energy levels."

Taylor discussed what their students needed to know related to their chosen topic, detailing how they made teaching choices regarding what content to bring into instruction.

- "From this prior knowledge, the only essential parts that students need to know are de Broglie's treatment of electron as standing waves and the implications of this when explaining how the electron remains in quantized energy levels."
- "Students should see the natural progression of ideas from Planck's initial proposal that energy is quantized, Einstein's quantization of light, and through Bohr's quantization of the atom."

Summary of KoCO

Taylor shared their KoCO by describing their teaching choices in regard to content and discussing the lack of state standards for their chosen topic. The main themes for KoCO were:

- Taylor was able to describe how their chosen topic fits into their existing unit on atomic theory.

- Because no state standard existed for their topic in chemistry courses, they described their own intended learning outcomes for their lesson on CHEM 770 topics.
- Taylor was able to describe the foundational components of their chosen topic that they would bring into instruction, thus making decisions about what content to teach.

These themes related to Taylor's KoCO, a component of their overall PCK. Their statements in their Teaching Script demonstrated improvements to their PCK through improved KoCO.

KoT

The next code is KoT, which involves the discussion of teaching methods and activities.[41] First, Taylor shared the teaching procedures related to their chosen lesson. They described how they would teach their topic, the reasoning behind their teaching choices, and the timeline for the lesson (which touches on their KoCO). This combination of knowledge bases demonstrates higher quality PCK.

- "Recalling the evidence we have already evaluated that supports Bohr's model (emission spectra). Explicitly identifying the problem that I know de Broglie's idea will help resolve. Continuously asking a series of guiding questions and engaging in a kind of Socratic dialogue. Supplementing abstract ideas with appropriate visuals and simulations that can make it easier to produce a mental model. Chunking the rationale and application of de Broglie's idea into several parts so it can become easier to understand and recognize its importance."

- "I would anticipate this taking one class period to understand how de Broglie's idea ties in with subatomic behavior."
- "At this point, pull up the PhET simulation on waves and simulate what is meant by the term 'standing wave.' To understand de Broglie's reasoning when connecting the idea of an electron as a wave to subatomic behavior, students need to have some kind of underlying concept of what a standing wave looks like. Play around with the simulation to show them standing waves of different wavelengths/frequencies."

Taylor also discussed which teaching strategies they would employ to address student misconceptions. Taylor brought in their KoSc, KoT, and KoR to correct anticipated misconceptions. This combination of knowledge bases demonstrated improvements to the quality of their PCK. Taylor also touched on their KoCO by sharing the lesson's organization in terms of time.

- "I would likely address this [misconception] by demonstrating a standing wave using the PhET simulation on waves."
- "I would likely address this [misconception] by showing them what it would look like for a standing wave orbiting an electron and in phase with itself compared to a different wave that is out of phase and therefore interferes with itself. This should help them recognize why only certain frequencies of light are able to excite the electron."
- "Prior to introducing anything related to de Broglie, make sure to explicitly establish the problem for students. Let them see the issue we are confronted with and rationale for needing to seek out an answer. This makes them part of the

process rather than just telling them new information that's disconnected from any real purpose. At this point, bring up the notes (PowerPoint) that begins with a brief dive into the photoelectric effect. After allocating 15-20 mins to the photoelectric effect and how Einstein would eventually resolve the issue it presented, make sure to bring these ideas together."

Summary of KoT

Taylor demonstrated their KoT by sharing how they planned to teach their chosen topic. The main themes for KoT were:

- Taylor was able to outline teaching procedures they would use in their instruction of a CHEM 770 topic.
- Taylor combined their KoSc, KoT, and KoR to address potential student misconceptions, which demonstrated improvements to the quality of their PCK.
- Taylor involved their KoCO in their KoT by discussing the timeline and overall organization of their planned lesson. This combination of knowledge bases demonstrated improved PCK quality.

Taylor demonstrated increased PCK quality by combining multiple knowledge bases during their description of their teaching plans.

KoA

The next code is KoA, which details teachers' knowledge of formal and informal assessments and feedback.[41] Taylor did not demonstrate any concrete KoA. The following statement possibly demonstrates some of the informal assessment they had planned for the lesson: "continuously asking a series of guiding questions and engaging in a kind of Socratic dialogue." This process of checking for understanding potentially connected to Taylor's KoA, but they did not explicitly describe any assessment methods. This reveals a potential gap in their PCK during their first semester in the MS program. However, they did express a strong understanding of PCK through their Semester 1 CoRe.

KoR

The final code in Codebook 2 relates to KoR, which discusses materials and activities that teachers utilize in their classrooms.[41]

- "Choosing from numerous available problems where students calculate various wavelengths of different objects."
- "Exploring the PhET simulation on wave-particle duality and diffraction as well as the simulation on the photoelectric effect."[71]
- "Choosing from numerous videos on YouTube to supplement de Broglie's idea and its relation to the series of quantum ideas that evolved during that time period."
- "At this point, I would show students this really nice video [link] of this same idea. I like the use of this video because it provides visuals and animations that I simply cannot."
- "I have attached the PowerPoint referenced throughout to the assignment."

Taylor is aware of multiple resources they could involve in their teaching, including simulations, videos, and PowerPoint notes.

Summary of Teaching Script Data

Upon creating a Teaching Script for a CHEM 770 topic, Taylor demonstrated multiple components of their PCK. The main themes from Taylor's Teaching Script were:

- Taylor developed a lesson using their new chemistry content knowledge that would best suit their students' learning and tie into their current atomic theory unit, which demonstrates KoSc, KoSt, and KoCO. This combination of knowledge bases demonstrates improvements to their PCK quality.
- Taylor's considerations of the content itself, their students' prior knowledge, their goals for the lesson, and specific teaching methods demonstrated their KoSc, KoSt, KoG, and KoT, which revealed improvements to their PCK. In addition, Taylor provided resources to supplement student learning, which connects to their KoR and demonstrated improvements to their PCK. Taylor's Teaching Script revealed their current level of PCK and indicated improvements to their PCK quality.
- The only component of PCK that Taylor did not include was their KoA. By not explicitly including any assessment methods in their description of their teaching procedures, Taylor potentially exposed a gap in their PCK. They did demonstrate their KoA in their Semester 1 CoRe, but they did not express their KoA unprompted in the Teaching Script module.

Module Survey – Teaching Script

After completing the Teaching Script assignment, Taylor was invited to complete a survey about their experience creating a Teaching Script for their topic. The Teaching Script module survey was coded using Codebooks 1 and 4.

Codebook 1

Coding frequencies for Codebook 1 can be found in Table 29.

Table 29. Module Survey Coding Frequencies for Semester 1 Teaching Script – CB1

Code	**Abbreviation**	**Frequency of Responses (*N* = 12)**	**Percentage of Total Responses (%)**
Attitudes	A-c	2	16.7
Knowledge	K-p	2	16.7
	K-c	3	25
Skill	S-c	1	8.3
Teaching	T	3	25
Modules	M	1	8.3
Reflection	R	1	8.3

Attitudes (A-c)

When asked about their confidence level on a scale of 1 to 6 for teaching their concept, Taylor responded with a score of 5.

Taylor shared one additional comment related their current attitudes. They demonstrated their KoSc, KoT, and KoA by discussing their confidence regarding teaching their chosen topic without preparation. This combination of knowledge bases demonstrated improvements to their PCK quality.

- "Though I think I could confidently explain it [without preparation], I wouldn't really have any confidence that any useful learning took place because this concept is so abstract."

Knowledge (K-p and K-c)

Taylor discussed their prior knowledge and the positive changes to their chemistry content knowledge that resulted from their participation in the CHEM 770 course. In these comments, they detailed improvements to their KoSc as a component of their PCK.

- "For this specific concept, it was a bit challenging for me because I didn't really have a firm understanding of it prior to taking this class. This course has certainly helped fill most of the gaps."
- "The content within this course helped fill some of the mental gaps present in my own mind about this concept. For a long time, I never really understood how an electron behaving like a wave provided any kind of explanation for why electrons remain in these quantized energy levels. Additionally, I never really knew why energy still wasn't emitted even though the electron was still orbiting."

Taylor mentioned that improving their chemistry content knowledge (KoSc) would help improve their teaching confidence.

- "I think I would feel more confident if I had a better understanding of standing waves in general."

<u>Skill (S-c)</u>

Taylor discussed how the CHEM 773 course gave them the content knowledge (KoSc) necessary to improve their pedagogical skill (KoT). By combining their KoSc and KoT, Taylor demonstrated improvements to their overall PCK quality.

- "This course helped clarify these ideas for me and will allow me to appropriately respond to questions and misconceptions from students on this topic."

<u>Teaching (T)</u>

Taylor discussed their teaching of their chosen topic by discussing the need to include visuals or simulations to improve student learning, combining their KoSt, KoR, and KoT. This combination of knowledge bases demonstrates improvements to their PCK quality.

- "I feel like it needs to be heavily supplemented with some kind of visuals or simulations for learners to comprehend what is going on."

To improve their teaching, Taylor discussed the desire to improve their KoSc and KoR. They combined these knowledge bases with their KoT, sharing their need for quality content knowledge (KoSc) and resources (KoR) in order to teach effectively (KoT). Their desire to improve these knowledge bases demonstrates their desire to improve the quality of their PCK.

- "I still needed to 'connect the dots' in ways that would make sense for me to explain and teach [the topic] to a group of students."

- "I think I would feel more confident if I had…some kind of activity or interactive simulation where students could engage with manipulating the standing waves within the atom and see how various amounts of energy are either absorbed or not based on the wavelength of the electron's standing wave."

Modules (M) and Reflection (R)

To conclude the Teaching Script survey, Taylor reflected on the value of the module. The Teaching Script allowed them to think deeply about their teaching of their chosen topic, especially taking into account their KoSt, KoSc, and KoT. Thus, the Teaching Script module enabled Taylor to improve their PCK.

- "I think the value in this module really comes from the fact that you have to sit down and 'play out' what you anticipate taking place when teaching the topic. As teachers, we do this all the time to a certain degree, but it's rarely so intentional. Scripting out what I plan to say and potential student responses allows for me to have a better overall idea to whether I actually understand the thing I'm talking about as well as my own awareness of whether I'm able to anticipate potential misconceptions that could arise from students throughout the lesson."

Codebook 4

Codebook 4 was used to identify the source of motivation that fueled Taylor's comments. Coding frequencies can be found in Table 30.

Table 30. Module Survey Coding Frequencies for Semester 1 Teaching Script – CB4

Code	Abbreviation	Frequency of Responses ($N = 11$)	Percentage of Total Responses (%)
Learning-focused	L-f	4	36.4
Student-focused	S-f	2	18.2
Teaching-focused	T-f	5	45.4

Taylor's comments included all three motivations, with five teaching-focused statements, four learning-focused statements, and two student-focused statements. An example of each motivation is given below.

- "This course helped clarify these ideas for me and will allow me to appropriately respond to questions and misconceptions from students on this topic." (T-f)
- "The content within this course helped fill some of the mental gaps present in my own mind about this concept." (L-f)
- "I feel like it needs to be heavily supplemented with some kind of visuals or simulations for learners to comprehend what is going on." (S-f)

Summary of Module Survey – Teaching Script

Through the Teaching Script module survey, Taylor shared their experience reflecting on and applying new knowledge from the CHEM 770 course. Taylor's responses to the module survey primarily focused on their own learning and teaching, but they also included statements describing the course's impact on their students' learning. The main themes from the module survey were:

- Improvements to Taylor's chemistry content knowledge (KoSc) led to improved PCK. Taylor also expressed their desire to further improve their KoSc and KoR, which indicates their desire to further improve their PCK in the future.
- Gaining content knowledge (KoSc) through the CHEM 770 course allowed Taylor to improve their pedagogical skill and teaching in general, demonstrating improvements to their KoSc and KoT, which improved their overall PCK quality.
- Taylor's confidence in their content knowledge comes from their KoSc and KoT, emphasizing their desire to be able to explain the concept to students effectively. Their comments reveal both their teaching philosophy and improvements to the quality of their PCK.
- The Teaching Script module allowed Taylor to reflect on how they would bring CHEM 770 topics into their teaching in a way that would best benefit student learning, again emphasizing improvements to the quality of their PCK through the intertwining of their KoSc, KoT, and KoSt.

Teaching Observation 1

<u>Pre-Observation Survey</u>

Upon scheduling the Zoom teaching observation, I sent the pre-observation survey to Taylor by email to complete prior to the observation. The pre-observation survey was coded using Codebooks 1, 2, and 4.

<u>*Codebook 1*</u>

Codebook 1 coding frequencies are shown in Table 31.

Table 31. Pre-Observation Survey Coding Frequencies for Observation 1 – CB1

Code	**Abbreviation**	**Frequency of Responses (N = 10)**	**Percentage of Total Responses (%)**
Attitudes	A-c	4	40
Teaching	T	6	60

Attitudes (A-c)

Taylor confirmed that they felt confident teaching their observed lesson and that "overall, [they] feel pretty good" about the lesson. Taylor reflected on their confidence in their students' skills and understanding of the content, stating their abilities to create plans for the inquiry activity. This statement demonstrates their KoSt as a component of their PCK.

- "I also feel that students understand stoichiometry well enough for me to have confidence in them that a reasonable plan can be generated."

They also shared their attitudes toward their students' ability to succeed during the observed lesson.

- "I'm confident the bulk of the class can do stoichiometry problems."

Teaching (T)

When presenting their lesson, Taylor touched on their KoCO by making choices about what content to focus on from their curriculum.

- “I will be introducing an investigation where students will be tasked with determining the correct chemical equation for the decomposition of sodium bicarbonate by applying their knowledge of stoichiometry.”

They also described the general structure of their lesson, which exhibited their KoT. They described their students’ involvement in the lesson, showing Taylor’s focus on student-centered learning.

- “Since students will be doing the heavy lifting when it comes to planning their investigation, it requires me to provide them with enough relevant information without giving too much away. This can be a tricky balance at times, but I really like the opportunity it provides for students to apply what they’ve learned in a novel way.”
- In the observed lesson, there is “nothing new besides general formatting stuff.”

Taylor demonstrated improvements to their PCK quality by taking their students’ prior knowledge into account when making choices about what or how to teach, which combined their KoSt and KoT.

- “Because of COVID and distance learning last year, most students have very weak lab skills. I’ll be accommodating for this by being intentional about certain lab information that they should be aware of to help them navigate the procedure they will develop.

Taylor further discussed their KoSt when anticipating their students’ reception of the lesson. This combination of their KoT and KoSt demonstrated improved PCK quality.

- “I anticipate a small fraction of them will recognize the pathway to take to determine the correct chemical equation. Though I’m confident the bulk of the class can do stoichiometry problems, it will take many of them longer to recognize how stoichiometry can be utilized to answer the guiding question."

Taylor described feeling confident in their teaching due to their past teaching experiences and KoT.

- "This is partly due to my prior experience with this lab and the fact that I like guiding discussions through various questioning techniques."

Summary of Teaching (T)

Taylor's pre-observation survey detailed their chosen teaching procedures for their observed lesson. The main themes for teaching were:

- Taylor demonstrated improvements to the quality of their overall PCK by integrating their KoSt, including students' prior knowledge and their anticipated reception of the content, and their KoT, which was evidenced by their description of teaching procedures and strategies.
- Taylor described their observed lesson, which involved student-centered learning through inquiry.

Codebook 2

Codebook 2 coding frequencies can be found in Table 32.

Table 32. Pre-Observation Survey Coding Frequencies for Observation 1 – CB2

Code	**Abbreviation**	**Frequency of Responses (*N* = 8)**	**Percentage of Total Responses (%)**
Knowledge of students	KoSt	3	37.5
Knowledge of curriculum organization	KoCO	1	12.5
Knowledge of teaching	KoT	4	50

Half of Taylor's responses to the pre-observation survey demonstrated their KoT, while just under half related to their KoSt. Taylor described how their KoSt informs their teaching choices, which demonstrates a combination of knowledge bases and, therefore, PCK. Upon sharing their lesson, they demonstrated their KoCO by situating the content within the context of their curriculum.

Codebook 4

Codebook 4 was used to demonstrate the motivations behind the teacher's comments. These coding frequencies are shown in Table 33 below.

Table 33. Pre-Observation Survey Coding Frequencies for Observation 1 – CB4

Code	**Abbreviation**	**Frequency of Responses (*N* = 9)**	**Percentage of Total Responses (%)**
Student-focused	S-f	4	44.4
Teaching-focused	T-f	5	55.6

Taylor's responses to the pre-observation survey reflected their motivations for their own teaching (55.6%) and their students' learning (44.4%). Taylor incorporated their students' prior knowledge and learning needs into their lesson plan, which demonstrates PCK.

Teaching Observation

All teaching observations were conducted via Zoom. Late in Taylor's first semester in the MS program, I conducted their first progress teaching observation to assess their current level of teaching effectiveness and identify any active PCK changes due to MS program impact. During the observation, I took notes guided by the Instruction domain of the Danielson Framework for Teaching Evaluation Instrument.[62] The notes of the teaching observation were then analyzed using Codebook 2. Codebook 2 coding frequencies can be found in Table 34.

Table 34. Observation 1 Coding Frequencies – CB2

Code	Abbreviation	Frequency of Responses (*N* = 22)	Percentage of Total Responses (%)
Knowledge of goals	KoG	2	9.1
Knowledge of curriculum organization	KoCO	4	18.2
Knowledge of teaching	KoT	7	31.8
Knowledge of assessment	KoA	9	40.9

KoG

Taylor described their KoG by communicating their goals to students during instruction. They explained to their students that the teacher would not give too much information to allow students to come up with their own explanations. They also allowed students to be creative in their thinking as the students prepared lab procedures for the following day.

KoCO

Taylor demonstrated their KoCO by communicating the course schedule and making decisions about what to teach. They communicated the schedule for the next few days of class for an investigation that would "solve a novel problem." They clarified the goal for the lab, connecting the activity to the course content. The observed class period was used to develop a plan for the lab that would be carried out the following day. They also communicated to students that the lab had been modified for different classes and then clarified the goal and purpose of the experiment for the current class.

KoT

Throughout the lesson, Taylor demonstrated their KoT in their teaching procedures and interactions with students. They communicated their learning expectations for students in relation to how they should perform calculations. After introducing a warm-up activity, they encouraged students to write down calculations as they worked. Students participated in discussion and Taylor used student responses in their explanations by referring to student answers. Before lab work, they explained expectations for lab safety and discussed lab procedures. Taylor then gave students an active role in the activity by presenting the lab and then giving students time and independence to complete prep work and create plans for lab procedure for the following day. When a question was brought up in a group, Taylor reiterated the question to the full class. When asking student groups about their plan for the lab procedure, Taylor redirected or rephrased questions when they did not receive clear answers. For example, Taylor asked students how they would figure out the mass of a solid inside of a test tube, demonstrated the situation, and then asked again.

KoA

Taylor demonstrated their KoA through informal assessments embedded in their instruction, as well as how they checked for student understanding throughout the lesson. They started class with a warm-up activity utilizing an online poll system involving student cell phones for a calculation question. They also checked for understanding throughout the lesson, including direct questioning while circulating the room during the discussion portion of the lesson to monitor student progress. They included assessment in activities by asking students to rationalize their plans or write any supportive reasoning for their lab procedures. Connecting to their KoT, they asked students about their procedures with redirecting questions to clarify student plans without immediately giving students a straight answer. By combining their KoA and KoT, Taylor demonstrated improvements to their PCK quality.

Post-Observation Survey

Once I was notified that the Zoom observation was complete, I sent Taylor the post-observation survey by email. The post-observation survey was coded using Codebooks 1, 2, and 4.

Codebook 1

Codebook 1 coding frequencies are shown in Table 35.

Table 35. Post-Observation Survey Coding Frequencies for Observation 1 – CB1

Code	**Abbreviation**	**Frequency of Responses (N = 7)**	**Percentage of Total Responses (%)**
Attitudes	A-c	1	14.3
Teaching	T	3	42.9
Reflection	R	3	42.9

Attitudes (A-c)

Taylor discussed their confidence level regarding the learning that took place during the observed lesson. After assessing student work, Taylor felt confident in their students' ability to apply chemistry skills. By demonstrating their KoSt, they indicated their PCK.

- "Based on my reading of preliminary investigation proposals that students generated during class, I'm confident that the majority of them are aware of how to apply stoichiometry to answer the overall guiding question for the lab."

Reflection

In the post-observation survey, Taylor reflected on how the lesson went, particularly focusing on learning outcomes. Taylor shared that the lesson went as expected "for the most part" and that they would "definitely" repeat this lesson the same way in the future.

- "Overall, [the] lesson went fine. By the end of the lesson, majority of groups at least had a grasp of what they were going to do in the lab and what to do with the data the next day."

Taylor also reflected on their own teaching, including adjustments they made during instruction to adapt to their students' needs, which related to their KoT and KoSt. This combination of knowledge bases demonstrated improvements to the quality of their PCK.

- "I hadn't originally intended to give them as much guidance as I actually did since I wanted them to be in a position where they really need to make the connection to stoichiometry on their own. That being said, I don't feel like I gave away so much information that they don't need to do any thinking. I just had originally wanted them to pull a bit more of their own weight."

<u>*Codebook 2*</u>

Codebook 2 coding frequencies can be found in Table 36.

Table 36. Post-Observation Survey Coding Frequencies for Observation 1 – CB2

Code	**Abbreviation**	**Frequency of Responses (*N* = 11)**	**Percentage of Total Responses (%)**
Knowledge of science	KoSc	1	9.1
Knowledge of students	KoSt	5	45.4
Knowledge of teaching	KoT	2	18.2
Knowledge of assessment	KoA	3	27.3

Taylor combined their KoSt and KoA by evaluating student work that took place during the observed lesson to assess student understanding or confusion. This intertwining of knowledge bases demonstrated improvements to the quality of their PCK.

- "Based on the investigation proposals I read, I would say roughly ½ fully understood what exactly they were going to do in the lab, ¼ had a good idea but didn't know exactly how to articulate it, and ¼ had trouble 'connecting the dots' even though they may have had the ability to do stoichiometry."

Taylor demonstrated their KoSt, KoA, and KoSc by discussing "three issues that stuck out most to" them after reviewing student work after class. These issues related to student misconceptions and reactions to the content. These knowledge bases demonstrated Taylor's PCK.

- "Some students had the misconception that if they just measured the mass before and after, that would indicate the amount of gas the left. While this is true, the misconception revolved around them thinking they could use that information to identify the identity of the gas. There was no realization that this simply wasn't possible given what lab equipment. It was a misapplication of stoichiometry and lab development."
- "Nearly all students recognized they needed the initial mass of their reactant. When describing to me what they were going to do after the reaction was complete, many failed to mention that they also need to determine the mass of their product, so they have something to compare their theoretical yields to."
- "A good portion of students inadequately articulated what exactly they intended to do in the lab. This is a very common theme with students. In their mind, they may know what they're going to do, but when I ask them to describe this process on paper, they summarize it in a way that is far too incomplete or ambiguous."

By combining knowledge bases, Taylor demonstrated improvements to the overall quality of their PCK.

Codebook 4

Codebook 4 was used to demonstrate the motivations behind the teacher's comments. These coding frequencies are shown in Table 37 below.

Table 37. Post-Observation Survey Coding Frequencies for Observation 1 – CB4

Code	**Abbreviation**	**Frequency of Responses (N = 11)**	**Percentage of Total Responses (%)**
Student-focused	S-f	5	45.5
Teaching-focused	T-f	6	54.5

Taylor's comments in the post-observation survey included teaching-focused (54.5%) and student-focused (45.5%) motivations. Their reflection of the lesson focused mostly on the effectiveness of their teaching choices and the quality of students' understanding of the lesson.

Summary of Observation 1

Taylor's first progress observation focused on students' preparation of a lab procedure to "determine the correct chemical equation for the decomposition of sodium bicarbonate." The main themes from Observation 1 were:

- Taylor expressed their confidence in students' prior knowledge and skill, demonstrating that they were aware of students' prior learning, how they would receive the observed lesson, and what student thinking occurred during the lesson. This reveals the presence of their KoSt as a component of their PCK.
- In accordance with their KoSt, their lesson exhibited aspects of Taylor's teaching philosophy and overall goals for student-centered learning. Students had independence and Taylor made intentional teaching choices to support their

students' independent learning, which showed a combination of their KoSt, KoT, KoG, and KoCO. This observed lesson and its associated surveys demonstrated the presence and intertwining of these PCK components, which indicated improvements to the quality of Taylor's overall PCK.

- Taylor's teaching included clear communication to students of expected learning outcomes and scheduling, again supporting Taylor's use of a student-centered teaching approach. These components of their lesson demonstrated their KoCO and KoT, which demonstrated their PCK.
- Assessment was integrated into the lesson plan. Taylor assessed students through multiple methods and was able to evaluate students' success with the learning objectives for the lesson, revealing Taylor's KoA.
- Taylor was also able to evaluate their own teaching and reflect on how their instruction departed from their plan for the observed lesson.

Taylor's comments before and after the lesson were split between teaching-focused (55%) and student-focused (45%) motivations. This observation further established a baseline for Taylor's PCK in practice. Although knowledge and skills gained during their first semester in the MS program may have impacted Taylor's PCK, any knowledge bases that were identified in this observation might not be attributed to the MS program itself.

End-of-Semester Survey

At the end of the Fall 2021 semester, I sent out an email invitation to participants of CHEM 770 and CHEM 771 to complete a survey about their experiences in core MS program courses and the MS program overall during the given semester. Taylor's responses to this survey were coded with Codebooks 1, 3, and 4.

Codebook 1

The frequency of responses to each code in Codebook 1 can be found in Table 38.

Table 38. End-of-Semester Survey Coding Frequencies for Semester 1 – CB1

Code	**Abbreviation**	**Frequency of Responses (*N* = 26)**	**Percentage of Total Responses (%)**
Attitudes	A-p	1	3.8
	A-c	1	3.8
Knowledge	K-p	1	3.8
	K-c	5	19.2
Teaching	T	1	3.8
Feedback	F	10	38.5
Modules	M	1	3.8
Interaction	I	2	7.7
Reflection	R	4	15.4

Attitudes (A-p and A-c)

Taylor discussed their teaching confidence prior to taking the CHEM 770 course.

- "This specific unit has always had a special place in my heart, and I had always felt reasonably confident about how I taught it."

Taylor then described improvements to their teaching confidence resulting from their participation in the course.

- "This class gave me the…confidence to help make changes to my atomic theory unit that will provide benefits in ways that I would have never incorporated otherwise."

Although Taylor already felt confident teaching atomic theory, the CHEM 770 course gave them the confidence to make changes to their unit. These comments indicated improvements to their KoCO as a component of their PCK.

Knowledge (K-p and K-c)

Taylor described improvements to their chemistry content knowledge (KoSc) due to both the CHEM 770 and CHEM 771 courses, which demonstrated improvements to their overall PCK.

- "770…gave me the knowledge…to help make changes to my atomic theory unit that will provide benefits in ways that I would have never incorporated otherwise. This class gave me a significant boost in my content understanding, which is something I had really hoped for. Like atomic theory, I was aware of a variety of ideas within the topic of intermolecular interactions, but never truly felt like I had a firm grasp on the finer points."
- "771 helped fill the gaps in my own understanding that provided all kinds of new ideas and applications to form in my head with respect to teaching."

When discussing impacts of the Fall 2021 courses, Taylor stated gaining knowledge from MS program courses that improved their chemistry content knowledge (KoSc) "significantly." Improved KoSc indicates improvements to their overall PCK.

- “Though my previous content knowledge certainly helped, the knowledge I acquired from both courses definitely exceeded my expectations.”
- “My chemistry content knowledge has improved significantly.”

Taylor mentioned that improvements to their content knowledge (KoSc) contributed to improvements to their teaching effectiveness. By combining their KoSc and KoT, Taylor indicated improvements to their PCK quality.

- “The fact that I understand the content so much better” improved their teaching effectiveness this semester.

<u>Summary of Knowledge (K-p and K-c)</u>

In the end-of-semester survey, the main themes for Taylor’s comments on knowledge were:

- The CHEM 770 and CHEM 771 courses strengthened Taylor’s chemistry content knowledge (KoSc), which improved their overall teaching effectiveness. Improving their KoSc improved their overall PCK.
- Improvements to Taylor’s KoSc and KoT demonstrated improvements to their overall PCK. The intertwining of these knowledge bases revealed improvements to the quality of Taylor’s PCK.

<u>Teaching (T)</u>

Taylor felt that the content learned in CHEM 770 would have an impact on their atomic theory unit, which showed improvements to their KoSc, KoT, and KoCO, thus improving their overall PCK.

- “770 exposed me to ideas within quantum theory that will undoubtedly have a significant impact on my atomic theory unit.”

Feedback (F)

Taylor shared ten comments coded as feedback. These statements were further analyzed using Codebook 3, which will be shared in the section below.

Modules (M)

Taylor described the impact of the CoRe and Teaching Script modules as allowing for reflection on their teaching, contributing to their KoT and KoCO and increasing their PCK.

- “Anything that required me to really reflect on my own teaching practices (CoRe assignment, Teaching Script, etc.) was meaningful because of the fact that I really had to reflect on what I do and how it might be altered.”

Interaction (I)

The MS program allowed for meaningful interactions with other teachers. These connections allowed Taylor to improve their KoSc, KoT, and KoR, which therefore enhanced their overall PCK. This combination of knowledge bases revealed improvements to the quality of Taylor’s PCK.

- “The social relationships developed with others from around the country has been really nice. Talking with other teachers who are going through the same course not only helps build my own understanding, but it creates opportunities to share ideas related to our current teaching practices.”

Reflection (R)

The end-of-semester survey allowed Taylor to reflect on their first semester in the MS program, as well as their thoughts leading up to starting the MS program. Taylor reflected on conversations they had with colleagues on their own master’s degree experiences, which Taylor felt departed from their own experience in the SDSU MS program.

- “Relative to what I have heard from colleagues throughout the years who had already completed their master’s degree, I felt these courses were significantly more challenging than what most programs offer teachers and I loved that. It gave me a greater sense that this was truly worth it.”
- “Based on the conversations with colleagues about what they did to complete their master's program while teaching, it always sounded like it wasn't a very challenging experience and felt more like a series of tasks they needed to complete in order to "check the box." That being said, I wasn't sure the level of rigor that I was going to experience. Part of me felt like I could rely upon my previous content knowledge acquired over the years and that would be enough to do well in the courses. This was definitely not the case.”

Taylor also described their interest in reading more research articles due to their exposure to more journal articles in the MS program. Exposure to educational research has the potential to improve Taylor’s KoT and KoR, which would improve their overall PCK.

- “Additionally, exposing me to research that I hadn't been aware of gave me the interest to consume other research articles.”
- “At this point, my pedagogical skill hasn't really changed that much but my experiences within the program so far have helped me reflect on what/how I currently do things that I may not have engaged in had I not taken these courses.”

Codebook 3

Taylor shared ten comments coded as “Feedback.” These statements were further analyzed using Codebook 3. These coding frequencies are shown in Table 39 below.

Table 39. End-of-Semester Survey Coding Frequencies for Semester 1 – CB3

Code	**Abbreviation**	**Frequency of Responses (*N* = 10)**	**Percentage of Total Responses (%)**
Assignment Feedback	AF	4	40
Course Feedback	CF	2	20
Program Feedback	PF	2	20
Logistical Feedback	LF	2	20

Assignment Feedback

Taylor first described the meaningful aspects of the Fall 2021 content courses. For both CHEM 770 and CHEM 771, they identified homework sets as challenging them to dedicate time to filling gaps in their chemistry content knowledge.

- “The HW Sets in both 770/771 were very meaningful to me because they were genuinely challenging. This forced me really confront what I didn't fully understand at that point in time. No other aspect of either course required as much of my time and the amount of learning that came out of doing these sets felt like it was time worth spent.”

They also discussed the value of the discussing content with other MS program participants, which positively impacted them “as a learner and a teacher.” These comments also related to the “Interactions” that were meaningful for Taylor’s learning.

- “The discussion boards in both 770/771 were also meaningful, but in a slightly different way. They were meaningful in the sense that it helped me to articulate my thoughts due the fact that I was writing. Additionally, reading the thoughts from other people helped me assimilate different ideas into my own understanding and expose my new ideas I hadn't previously considered. This was helpful both as a learner and a teacher.”

The modules and pedagogical assignments allowed Taylor to reflect on their own teaching.

- “Anything that required me to really reflect on my own teaching practices (CoRe assignment, Teaching Script, etc.) was meaningful because of the fact that I really had to reflect on what I do and how it might be altered. Having this opportunity to reflect has significant value.”

Finally, they highlighted the value of discussing chemical education research papers in CHEM 771.

- “Additionally, I really liked the fact that in 771 we were exposed to actual research papers that required us to engage with the research, reflect on it, and apply to current teaching practices.”

<u>Course Feedback</u>

Taylor discussed the challenging level of the Fall 2021 content courses, which they felt gave CHEM 770 and CHEM 771 high value for money.

- "For both courses, I genuinely felt like these were treated as 'master-level' courses. Relative to what I have heard from colleagues throughout the years who had already completed their master's degree, I felt these courses were significantly more challenging than what most programs offer teachers and I loved that. It gave me a greater sense that this was truly worth it."

They also felt that the MS program's focus on chemistry content exceeded their expectations.

- "The fact that the program really emphasizes deepening our content knowledge as teachers is really awesome and that's probably the part that exceeded my expectations the most."

Program Feedback

Taylor felt that nothing failed to meet their expectations in the Fall 2021 semester.

- "There wasn't really anything that I would label as 'not meeting my expectations.' The classes were challenging, the professors were clearly knowledgeable and responsive, and at no point did I find myself questioning the decision I made to join this program."

In comparison to colleagues' master's programs, Taylor felt that the MS program challenged them beyond their expectations.

- "Based on the conversations with colleagues about what they did to complete their master's program while teaching, it always sounded like it wasn't a very challenging experience and felt more like a series of tasks they needed to complete in order to 'check the box.' That being said, I wasn't sure [of] the level of rigor that I was going to experience. Part of me felt like I could rely upon my previous content knowledge acquired over the years and that would be enough to do well in the courses. This was definitely not the case."

Logistical Feedback

In terms of aspects of MS courses that were not meaningful to Taylor, they elaborated on the frequency of discussion boards in CHEM 770.

- "While the discussion boards had value, I felt that the frequency with which they were used in 770 wasn't necessary to attain the value they provided. I really liked the Gribbin discussion boards and I can understand the weekly requirement for these so that we stay on top of the reading, but I felt the weekly content discussion boards could've been less frequent and still maintained their worth."

Taylor also suggested having more uniformity between MS program courses in terms of course organization and communication, especially due to its virtual format.

- "One of the things I might change is to ensure some kind of uniformity between different classes with respect to how class information is organized and communicated. Since both 770/771 organized content differently (ex. Weeks vs. Units) and communicated differently (ex. Course updates within D2L vs. email updates), it can become difficult to keep track of things like due dates, expectations, and updates in general. This is more of a logistical thing and really only applies to a program like this because of its mostly online format."

Codebook 4

Codebook 4 was used to analyze Taylor's motivations for statements made in the end-of-semester survey. Coding frequencies can be found in Table 40.

Table 40. End-of-Semester Survey Coding Frequencies for Semester 1 – CB4

Code	Abbreviation	Frequency of Responses (N = 16)	Percentage of Total Responses (%)
Learning-focused	L-f	10	62.5
Teaching-focused	T-f	6	37.5

Taylor did not include any student-focused motivations in their responses to the end-of-semester survey. Most of their comments related to their own learning (62.5%), while the remaining 37.5% of comments focused on their teaching. Some examples are given below of each motivation.

- "Anything that required me to really reflect on my own teaching practices (CoRe assignment, Teaching Script, etc.) was meaningful because of the fact that I really had to reflect on what I do and how it might be altered." (T-f)
- "This class gave me a significant boost in my content understanding, which is something I had really hoped for." (L-f)

Summary of End-of-Semester Survey

The end-of-semester survey gave Taylor an opportunity to reflect on their first semester in the MS program in terms of content knowledge gain, impacts on their teaching, and reflection on their experience in MS program courses. When sharing their experience from their first semester, Taylor mainly described impacts on their own learning and teaching and did not discuss any implications for their students' learning. The main themes for Taylor's Fall 2021 end-of-semester survey were:

- Through the MS content courses, Taylor gained chemistry content knowledge which improved their teaching confidence and enabled them to enhance their teaching effectiveness through increased KoSc, KoT, KoCO, and KoR. These improvements demonstrated increased PCK. The combination of these knowledge bases revealed improvement to the quality of Taylor's overall PCK. The focus on chemistry content in the MS program exceeded Taylor's expectations.
- Taylor planned to bring new content knowledge and teaching strategies into their instruction due to their experience in the MS program. The combination of Taylor's KoSc and KoT demonstrated improvements to the overall quality of their PCK.
- Interacting with other teachers in the MS program allowed Taylor to improve their content understanding and gain new ideas that they could bring into their teaching, demonstrating improvements to their KoSc, KoT, and KoR, which enhanced the quality of their overall PCK.
- When reflecting on their colleagues' experiences in other master's programs, Taylor felt that their experience in the SDSU MS program had higher value due to the inclusion of rigorous content, exposure to research, and the ability to reflect on their teaching practices.
- Taylor found the homework sets, discussion forums, and module assignments meaningful in the CHEM 770 and CHEM 771 courses. In CHEM 771, they

appreciated the inclusion of educational research papers, which they could apply to their own teaching.

- In terms of suggested changes, Taylor hoped for fewer discussion forums in CHEM 770 and greater uniformity between courses in terms of organization and communication.

Summary of Semester 1

During Semester 1, Taylor participated in the CHEM 770 discussion forums, the CoRe and its module survey, the Teaching Script and its module survey, the end-of-semester survey, and their first progress observation and its surveys. The main themes for their first semester in the MS program were:

- Taylor gained chemistry content knowledge (KoSc) from the CHEM 770 and CHEM 771 courses, which improved their teaching confidence and allowed them to become a more effective educator by increasing their KoSc and therefore enhancing their PCK.
- Taylor planned to incorporate knowledge and skills gained in the MS program into their instruction, which reveals the professional impact of the MS program and shows that they had intentions to apply their MS program experience to their teaching. This combination of KoSc, KoR, and KoT demonstrated improvements to the quality of Taylor's PCK that they could actively implement into their instruction.
- Interactions with fellow MS program participants supported Taylor's gain of resources (KoR), teaching strategies (KoT), and content understanding (KoSc), showing that these interactions led to improved PCK.

- Through module surveys and observation surveys, Taylor was able to reflect on their current teaching practice and discuss how they could bring in new content, skills, and knowledge into their teaching plans, again showing a direct impact of the MS program on a participant's professional development. This reflection reveals the process of Taylor's development of PCK through the MS program. Taylor gained knowledge and skills, reflected on how they could bring this knowledge into their teaching practice, and, therefore, experienced PCK growth and enhanced PCK quality.
- Each of the data collection methods showcased Taylor's presence of components of PCK, which confirmed the presence of Taylor's PCK during their first semester in the MS program. Taylor's experience in the MS program during Semester 1 led to increases in separate components of PCK, as well as the intertwining of knowledge bases, which indicate improvements to the quality of Taylor's PCK.

Semester 2

During Semester 2, Taylor participated in one chemistry content courses, CHEM 772, which focused on thermodynamics topics. They also participated in a pedagogical course, CHEM 778, which focused on chemistry teaching strategies. These courses were fully online and primarily asynchronous. Weekly Zoom sessions were offered for each course, with the CHEM 778 sessions being required, and were the only synchronous components. The data for Semester 2 is presented chronologically. Two check-in interviews took place via Zoom at the beginning and end of Semester 2. Taylor participated in their second progress teaching observation, along with pre- and post-observation surveys, near the end of the semester. The CoRe and Teaching Script assignments were both administered in CHEM 772 near the middle and end of the semester, along with module surveys. The End-of-Semester survey was sent out after the conclusion of the semester. Table 41 discusses the methods used during the Semester 2.

Table 41. Semester 2 Data Collection Methods

Term	**Data Collection Methods**	**ID Codes**
Semester 2	**CHEM 772:**	
	CoRe	CoRe
	Module Survey	MS
	Teaching Script	TS
	Module Survey	MS
	CHEM 778:	
	Midway Course Reflection	MCR
	General:	
	Check-in Interview 1	I
	Check-in Interview 2	I
	Teaching Observation	TO
	End-of-Semester Survey	EOS

Check-in Interview 1

At the beginning of Semester 2, I interviewed Taylor via Zoom to learn more about their experience in the MS program during Semester 1 and their goals for their time in the MS program in Semester 2. The first check-in interview was coded using Codebooks 1, 3 and 4.

Codebook 1

Codebook 1 coding frequencies are shown in Table 42.

Table 42. Check-in Interview 1 Coding Frequencies – CB1

Code	**Abbreviation**	**Frequency of Responses (*N* = 38)**	**Percentage of Total Responses (%)**
Attitudes	A-p	2	5.3
	A-c	5	13.2
Knowledge	K-c	2	5.3
Goals	G	5	13.2
Background	B	3	7.9
Experience	E	3	7.9
Teaching	T	6	15.8
Feedback	F	3	7.9
Modules	M	1	2.6
Interaction	I	1	2.6
Reflection	R	7	18.4

Attitudes (A-p and A-c)

When reflecting on their experience in the MS program so far, Taylor shared positive attitudes.

- "Good. I thought [Semester 1] went well grade-wise. It went just fine."
- "I don't have any real concerns. It's been really nice so far."
- "I'm excited for the program that I chose, so it's good."

Their experience in the CHEM 771 course increased their confidence in their chemistry content knowledge, which would allow them to incorporate intermolecular forces more into their instruction. This reveals a combination of their KoSc and KoT, which highlights improvements to the quality of Taylor's overall PCK.

- "So now me feeling more confident with [intermolecular forces] has given me kind of a greater sense of responsibility to incorporate that more often."

Taylor described their hope for the program to be primarily focused on chemistry, with an emphasis in teaching, which the MS program fulfilled.

- "Personally, I was really hoping for a strong emphasis, basically treating it like a master's in chemistry, so to speak, with an emphasis in teaching. [The MS program] seems to be much more in line with what I was hoping for."

In getting started on their action research project, Taylor shared their hope for positively impacting their students through research. They also described feeling a loss of motivation for pursuing research in the classroom if there is a lack of support and accountability. This statement demonstrated Taylor's KoG, which indicates the presence of their PCK.

- "When there's nobody checking on me and helping me evaluate that stuff and build those skills it's really easy to lose motivation in potential interest for [doing research in the classroom], and so I think getting a clear idea on a potential research project that I'm interested in and can significantly impact my students in a positive way is something that I'm really, really hoping for."

Summary of Attitudes (A-p and A-c)

In the first check-in interview, Taylor expressed their attitudes toward their experience in their first semester in the MS program and their hopes for the current semester. The main themes for attitudes were:

- Taylor shared positive attitudes toward their experience in the MS program in Semester 1.
- Taylor described their desire to gain chemistry content knowledge (KoSc) through the MS program, which did take place during Semester 1, which improved their PCK. Their increased content knowledge led to increased teaching confidence, demonstrating the impact of the MS program on Taylor's teaching. By combining their KoSc and KoT, Taylor demonstrated higher quality PCK resulting from their first semester in the MS program.
- Taylor discussed their hope for gaining interest in conducting educational research in their own classroom, particularly through the action research project component of the MS program. Their description of conducting research to improve student learning connects to their KoG, a component of their PCK.

Knowledge (K-c)

Taylor described chemistry content knowledge (KoSc) that they gained in the CHEM 770 and CHEM 771 courses in the Fall 2021 semester. They discussed strengthening existing knowledge and gaining new knowledge as well. The content knowledge takeaways from these courses were valuable for Taylor by giving them the ability to make stronger connections between chemistry topics in their teaching, which combines their KoSc, KoCO, and KoT, indicating improvements to the quality of their PCK.

- "It was really nice to have not just a content refresher but be introduced to new ideas from the content point of view as well… some of those higher level concepts that you may not fully teach ever but are worthwhile knowing for a variety of different reasons to make those connections that was really nice. But even the new ones that maybe I didn't previously teach and I'm more so thinking about like the quantum mechanical stuff [from CHEM 770]."
- "And then [CHEM 771] was really nice as well because they play such an important role in so many different topics from gases to solutions to topics that we cover."

Goals (G)

Taylor connected their goals to their teaching, which demonstrated their current level of PCK. They also had a goal to apply the KoSc they gained in the MS program to their teaching (KoT), which revealed an improvement to the quality of their overall PCK.

- "One of my goals was to obviously build a better foundation of content knowledge. But then, in the context of teaching the things that I learned content wise, how can that be applied, because it doesn't really matter if I can't find a way to apply it in some way to my job and I think the pedagogical stuff."

Taylor then shared their goals for Semester 2, including preparing for their action research project, gaining knowledge of thermodynamics topics (KoSc), and gaining research skills that could be employed after the MS program.

- "I think that the bulk of what I'm going to take out of this spring semester is obviously I want to have a really clear idea about the potential research project that I'm going to do. I obviously haven't done research since college and so getting a refresher on how that process works again and all the little logistical things."
- "Obviously gaining a better idea of thermo stuff is going to be nice as well."
- "Getting a more firm idea of how to do research so that when the program is all said and done, I feel and I want to do my own kind of action research, so to speak. I can do that in still an informal way but do it in a way that I can be confident about testing my students and seeing how certain changes are being made, but I really do want to make some pedagogical changes that I really put the time and effort into thinking about in having it shift beyond 'Well, this is a cool idea I'm going to do it' to 'this is a cool idea. here's why I'm going to do it. I did it. What impact did it have? Do I need to tweak it?'"

<u>Summary of Goals (G)</u>

Taylor discussed goals for their time in the MS program, particularly for Semester 2. The main themes for goals were:

- Taylor hoped to gain greater content knowledge which they could apply to their teaching, indicating an increase in their PCK quality through a combination of their KoSc, KoCO, and KoT. They explicitly described the value of gaining content knowledge for their professional use.
- Taylor had goals to refresh their research skills to begin their action research project. Gaining these skills would allow Taylor to conduct action research in their own classroom, demonstrating their KoG and KoT and revealing their desire to better understand the impact of their pedagogical changes. Their combination of knowledge bases indicated an improvement to the quality of their PCK.

Background (B)

When reflecting on their experience in the MS program in Semester 1, Taylor shared details of their educational and teaching background. Taylor first quantified their level of teaching experience.

- "In my case I would have graduated college in 2012 and so you know, it being roughly 10 years and then doing a certain level of content for roughly 10 years."

They then discussed the impact the CHEM 771 course would have on their ability to advocate for an emphasis on intermolecular forces topics in chemistry courses at their school, which demonstrates their KoCO as a component of their PCK.

- "At least in my school and my context in my department, we haven't really placed a strong emphasis on intermolecular forces - not just knowing what they are, but the how particles interact with each other in that particular way. And that's something that I've wanted to advocate for - or I have advocated for years."

When discussing their teaching context, Taylor shared details of their school's science department within the context of their school.

- "Chemistry teachers - technically there's seven or eight. My high school is almost 3000 students, it's one of the biggest in [state]. Traditionally, there's four or five of us that teach chemistry. This is a unique year just because we have more sections of it so there's some people that are only teaching one section so that's why there's seven or eight of us, but they have a license. They mainly teach physics, but they're also technically licensed in chemistry so they can do it. So typically around five. And then, in the science department, I think it's 16 or something like that."

<u>Experience (E)</u>

Taylor described their progress with MS program requirements in terms of courses during the first two semesters of their experience.

- "So, up until now, I have completed Chem 770 and 771 (so that was the atomic theory and intermolecular forces) those went just fine and then for the spring of 2022 I'm signed up for 778 (Chem teaching strategies), 772 (thermo) and I think 777, which is the action research class so that's what's going on this spring."

Taylor described the status of their action research project, stating their plans to begin reflecting on research options.

- "Not even brainstorming yet. So this is week one and I have the book. I have my meeting scheduled with Instructor B next Friday and so I'm planning to this weekend just dive into the book a little bit, and I've very subtly thought about some things as to what I could do."

They then discussed their experience in the MS program in terms of progress they have made toward their goals for engaging with chemistry educational research. They specifically focused on the use of journal articles in the CHEM 771 course. This interaction with the literature enabled Taylor to further develop their KoSc and KoT, which led to improvements to the quality of their PCK.

- "One thing I really liked about [CHEM 771] was that we would actively engage in reading like actual research papers and whatnot and not getting super in depth with them because it's not like a research class, but just saying 'hey here's this research paper on this particular topic that we happen to be studying right now, and why doesn't oil dissolve in water' and using that research in the context, because it was usually from the *Journal of Chemical Education*. It wasn't your typical ACS journal that was meant for chemists. It was clearly meant for chemistry educators."

Summary of Experience (E)

Taylor shared details about their experience in the MS program so far. The main themes for experience were:

- Taylor outlined their progress in MS program courses, as well as the anticipated start of their work on their action research project.
- Taylor discussed the impact of the CHEM 771 course on their ability to interact with chemical education research, which related to their goal to gain knowledge of the research process that could be applied to their own teaching. This combination of their KoSc and KoT demonstrated improvements to the quality of their PCK.

Teaching (T)

Two of Taylor’s comments connected to their KoCO by discussing connections between the Fall 2021 courses and their teaching choices. Relating to the CHEM 770 course, Taylor discussed reworking their unit based on knowledge gained of CHEM 770 topics (KoSc). By combining their KoSc and KoCO, Taylor demonstrated improvements to the quality of their PCK.

- “I've thought a lot about how to rework my quantum unit, or the atomic theory unit, based on what I learned throughout that atomic theory class.”

Taylor also reflected that their teaching of gases and learning of gases in CHEM 771 coincided, so they were able to apply new content knowledge to their instruction, showing a direct impact of the MS program on Taylor’s teaching. By combining their KoT and KoSc, Taylor demonstrated improvements to the quality of their PCK.

- “We were studying gases in Honors chemistry, while I was learning about gases in Instructor B’s class (771) and so that was nice to be able to take some of the like the Van der Waal’s stuff and incorporated into what I was currently doing.”

Taylor discussed their current inclusion of research methods they carry out in their classroom, which they hoped to build on through the MS program. These statements combined Taylor’s KoG and KoSt, which indicated improvements to their PCK quality.

- “I like data and so I've always really wanted to - and have tried to different degrees - gather data on my students on conceptual exams that were made by some third party so, for example I think it's the conceptual exam given out by ACS, so it wasn't designed by me, but if I give it pre/post each year. Or the classroom tests scientific reasonings so seeing how my kids' reasoning skills are improved from year to year."

Summary of Teaching (T)

Taylor discussed their teaching in terms of the impact of the MS program courses and their current teaching methods. The main themes for teaching were:

- The CHEM 770 and CHEM 771 courses impacted Taylor's current and future teaching of these course's topics. Taylor combined their KoCO, KoT, and KoSc, which demonstrated improvements to their PCK quality.
- Taylor discussed the current educational research they conduct in their classroom, revealing a baseline for their action research that they hoped to improve upon through the MS program. By combining their KoG and KoSt, Taylor demonstrated improvements to the quality of their PCK.

Feedback (F)

Taylor shared three comments coded as feedback. These statements were further analyzed using Codebook 3, which will be shared in the section below.

Modules (M)

Taylor referenced the CoRe module and described how it prompted them to reflect on their current teaching practice and think about their reasoning behind their teaching choices. The CoRe allowed them to intertwine their KoCO and KoT, which demonstrated improvements to their PCK quality.

- "There have definitely been some things, like one of those CoRe assignments that we did, where it really required you to reflect on what you currently do and then ways in which you could improve that, but it was more specific than that, like what would you do here and then what you know, why would you do it."

Interaction (I)

Taylor reflected on the value of discussing content (KoSc) and teaching (KoT) with other MS program participants, also referencing teacher-initiated study sessions, which demonstrated interactions between teachers that took place outside of the MS program requirements. These interactions allowed Taylor to experience professional development and supported their PCK growth.

- "Just getting to know some other teachers it's not like a great deal of other teachers, but we would have with these weekly study sessions, and though that helped me as a student, it was also nice to talk about teaching stuff and it's always easy to hit the ground running with other teachers, because you have these similar experiences, especially with the pandemic and whatnot so just talking about different ideas and that's been kind of stimulating on its own."

Reflection (R)

The check-in interview allowed Taylor to reflect on their experience in their first semester in the MS program, as well as their current teaching practice and hopes for their second semester at SDSU. Taylor reflected that the focus of the MS program on content exceeded their expectations.

- "It was what I had anticipated. Nothing was beneath my expectations. I guess you could say is exceeding I really liked the fact of how much it stressed content. When you're initially applying for to get a master's in teaching chemistry, I think there's this initial thought of kind of wondering that 'Okay, maybe it's going to be a bunch of pedagogical related classes.'"

They described having a positive experience in the MS program, particularly related to the "intellectually demanding" nature of the content courses. Taylor felt that this exposure to challenging content would allow for their growth, indicating potential improvements to their KoSc and overall PCK.

- "It's been a really good experience so far and, for what it's worth, I feel like the program in and of itself, even though I've only been through a semester of it just based on what I've heard and what I see now in the spring, I'm glad that it feels more intellectually demanding than maybe some of the other master's programs that I've heard over the years that maybe my colleagues have completed, where you just do these courses online and so in one sense it's more challenging which places additional stress on you, because you're teaching, but at the same time it's going to be for the better that it's more challenging and so I see a lot of opportunity for growth in it."

Taylor reflected on the challenges posed by the content courses and anticipated the difficulty of the thermodynamics content that they would engage with through CHEM 772 in Semester 2.

- "The level of depth that we went into, even though it wasn't calc[ulus] based or anything like that, it was still pretty intellectually demanding and I think that's just a natural part of what the topic was, so it wasn't as intellectually demanding as intermolecular forces, but again I think that's just because it was the quantum stuff so it'll be interesting to compare that to thermo, which, again, I don't think it's as abstract as the quantum stuff. But you know it's also a little bit more abstract to me than it was the intermolecular stuff and so it'll be interesting to evaluate those two."

They also reflected on the action research component of the MS program, which they began to learn more about during their second semester.

- "I just need to look more closely at what the research project is even fully about and what the parameters are to even begin sort of thinking about what I want to do."

Taylor related their experience in the MS program to their teaching, in terms of research and teaching procedures. Reflecting on their teaching practice and chemical education research enabled Taylor to enhance their KoSt and KoT, which demonstrated improvements to their overall PCK quality.

- "It was nice to be able to read actual research in the context of how students, either at the college level or high school level did on that particular topic or how they thought about it and then kind of transfer that or apply it or assimilate it into my way of thinking in relation to my class."
- "Any moments of forceful reflection or intentional reflection that's helped me think about what I'm doing currently" has been beneficial.

They more specifically reflected on the delayed impact of the MS program by discussing when they expect to reap the benefits of their experience in MS program courses.

- "I think a lot of the benefits are going to come the year after I complete either the program or the year after I complete the first year of the program because it'll be a new school year…The atom won't come up until fourth quarter and we're not even there, so I haven't seen the repercussions of that until fourth quarter."

Summary of Reflection (R)

Taylor looked back on their experience in their first semester in the MS program and reflected on their hopes for the coming semester. They also shared thoughts about their current teaching. The main themes for reflection were:

- The MS program offered an opportunity for science teachers to gain a greater depth of chemistry content knowledge (KoSc), which differed from other MS programs for chemistry teaching. Taylor reflected that the MS program exceeded their expectations by being "intellectually demanding" and having a stronger focus on content. These comments demonstrated Taylor's belief that the MS program allowed participants to develop KoSc, which improved their overall PCK.
- Taylor reflected on how the MS program had allowed them to learn more about chemical education research and think about their current teaching practice. This exercise enabled them to enhance their KoSt and KoT, which improved the quality of their PCK. They also shared that they were not able to see the impact of the MS program on their teaching until later in the school year.

Codebook 3

Taylor shared three comments coded as "Feedback." These statements were further analyzed using Codebook 3. These coding frequencies are shown in Table 43 below.

Table 43. Check-in Interview 1 Coding Frequencies – CB3

Code	**Abbreviation**	**Frequency of Responses (*N* = 3)**	**Percentage of Total Responses (%)**
Program Feedback	PF	1	33.3
Logistical Feedback	LF	2	66.7

Program Feedback

Taylor shared positive feedback about the MS program after their first semester.

- "It's been a really good experience so far. Even though I've only been through a semester of it, I'm glad that it feels more intellectually demanding than maybe some of the other master's programs that I've heard over the years that maybe my colleagues have completed, where you just do these courses online. In one sense it's more challenging which places additional stress on you because you're teaching, but at the same time it's going to be for the better that it's more challenging. I see a lot of opportunity for growth in it, so I'm excited [about] the program that I chose, so it's good."

Logistical Feedback

In terms of logistical feedback, Taylor emphasized their desire for logistical uniformity across MS program courses. They acknowledged each instructor's "autonomy," but emphasized the value of uniformity in an online program.

- "You can tell that there's an effort being made amongst the professors to try to have some uniformity for logistical things between classes. Everybody's going to have a certain degree of autonomy, obviously, but just purely logistical things having some uniformity and so that from a student point of view, especially when you're trying to learn remotely, it makes it really difficult. It's like "well do I find it here? do I find it here?" But the professors so far have always been very responsive and quick to respond to things like that and try and being clear on things. It places that additional responsibility upon you as a student to be like, 'okay, how do I find everything and where do I go.' That could be something as simple as Instructor B organizes them by weeks, but Instructor A organizes them by units, but then if it says unit one, that's not really unit one in the book. As long as you have a clarity on that you're fine. It would be nice to have some uniformity. I saw for 772, how Instructor C organizes it is again a little bit different, so again obviously autonomy."

Taylor further discussed the importance of uniformity in the remote setting, with examples focusing on assessments.

- "I only think [uniformity] is more of a pressing concern purely because it's remote. Obviously, there's [sic] logistical things that you'd want to keep in line even if it was in person, but because it's mainly remote you want to try and eliminate as many obstacles as possible. If that's in our control as educators and if it's not like you have to do all this extra work… One thing that's been nice is you can tell that there's some kind of uniformity between how they grade. The rubrics for discussions, things like that are nice, but even assessments: one professor will allow one retake, one will allow no retakes, the other allows ten opportunities and so again, it just is like 'okay, what does that person want?' But what does it mean

> in terms of education? Are you at a disadvantage or there's some kind of educational advantage…why do you offer one and you offer ten and you offer zero? I'm not saying one is right and one is wrong. I'm just saying all three of them can't be right to the same extent, and so what is the most reasonable solution for this? If it's none, cool, if it's ten, cool."

Codebook 4

Codebook 4 was used to demonstrate the motivations behind the teacher's comments. These coding frequencies are shown in Table 44 below.

Table 44. Check-in Interview 1 Coding Frequencies – CB4

Code	**Abbreviation**	**Frequency of Responses (*N* = 29)**	**Percentage of Total Responses (%)**
Learning-focused	L-f	16	55.2
Student-focused	S-f	2	6.9
Teaching-focused	T-f	11	37.9

Taylor primarily shared learning-focused (55.2%) and teaching-focused (37.9%) motivations resulting from their experience in the MS program in Semester 1. They also discussed their hopes for Semester 2 related to learning more skills and knowledge to apply to their teaching. Two of their comments related to implications for their students' learning. An example of each code is given below.

- “It was really nice to have not just a content refresher but be introduced to new ideas from the content point of view as well.” (L-f)
- “I've thought a lot about how to rework my quantum unit, or the atomic theory unit, based on what I learned throughout” CHEM 770. (T-f)
- “Getting a clear idea on a potential research project that I'm interested in and can significantly impact my students in a positive way is something that I'm really, really hoping for.” (S-f)

Summary of Check-in Interview 1

Taylor’s first check-in interview took place between their first and second semesters in the MS program. They reflected on their experience in the MS program in Fall 2022 and anticipated the future impact of the MS program. Taylor’s comments focused primarily on their own learning (55.2%) and teaching (37.9%), but they also discussed the MS program’s impact on their own students’ learning. The main themes from Check-in Interview 1 were:

- The MS program is unique in its focus on helping science teachers develop stronger content knowledge (KoSc), which is necessary to enhance PCK.
- For Taylor, gaining content knowledge in the MS program courses led to increased teaching confidence and improved teaching effectiveness. They applied new and refreshed knowledge to their teaching, indicating higher quality PCK by combining their KoSc, KoT, and KoCO.
- Learning more about chemical education research helped Taylor make progress toward their goal to conduct more action research in their own classroom. They

gained research knowledge and skills, which aligned with their KoG and KoT, two aspects of their PCK.

- Interactions with other MS program participants extended past the requirements of the MS program and impacted Taylor's content and pedagogical knowledge. Allowing for teachers to learn in community with one another impacted teachers' PCK by improving their KoSc, KoT, and KoR through the exchange of knowledge.
- Taylor shared positive feedback on the "intellectually demanding" nature of the MS program, but expressed their desire for more logistical uniformity across courses in terms of organization, communication, and assessment.

CoRe

In Spring 2022, the CoRe was administered midway through the CHEM 772: Thermodynamics course. The CoRe was analyzed using Codebook 2 to assess Taylor's PCK. Table 45 displays the codes from Codebook 2 that appeared in Taylor's Semester 2 CoRe.

Table 45. CoRe Coding Frequencies for Semester 2 – CB2

Code	**Abbreviation**	**Frequency of Responses (*N* = 32)**	**Percentage of Total Responses (%)**
Knowledge of science	KoSc	13	40.6
Knowledge of goals	KoG	1	3.1

Knowledge of students	KoSt	8	25
Knowledge of curriculum organization	KoCO	1	3.1
Knowledge of teaching	KoT	4	12.5
Knowledge of assessment	KoA	3	9.4
Knowledge of resources	KoR	2	6.3

KoSc

The first component of PCK represented in the CoRe is KoSc, which includes science content, scientific practice, the nature of science, and scientific progress.[41] Taylor chose to create a CoRe on Hess's Law. They then described why they believe teaching Hess's law would be challenging. Their statements below reveal connections they made between their KoSc and KoT, which reveals improvements to the quality of their PCK.

- "Requires an attention to detail both symbolically (manipulation of chemical equations and direction/magnitude of heat), and mathematically (calculating enthalpies from experimental data or using known enthalpy values). Correctly answering questions involving Hess's Law is typically the result of doing several little steps correctly along the way. If attention to detail is not adhered to, or not well understood, a given problem will quickly result in being wrong. Any multi-step problem, especially when it relies on abstract ideas, is going to be a challenge at this level."

- "Given a chemical equation, being able to anticipate how other chemical equations with known enthalpy values could be manipulated to add up to the original chemical equation."

Taylor also demonstrated their KoSc by describing the intended learning outcomes for this lesson.

- "Apply Hess's Law to determine the change in enthalpy for a given reaction (ΔH_{rxn})."
- "Be able to manipulate intermediate chemical equations so that, when added, the net reaction reflects the primary reaction of focus."
- "Recognize that changes made to chemical equations will also require changes to be applied to the enthalpies of those reactions."
- "Understand that a negative enthalpy change indicates an exothermic process and a positive enthalpy change corresponds to an endothermic process."

Taylor shared the additional KoSc they possessed beyond what they would teach in their classroom.

- "Enthalpy is a state function. Because of this, the enthalpy change of a reaction is independent of the pathway taken from the initial to final state of the reaction. This is ultimately why Hess's Law is able to be applied successfully."
- "Hess's Law is an expression of the 1st Law of Thermodynamics. Though I would discuss this in the context of conservation of energy, I would not expect students to understand how Hess's Law is an expression of the 1st Law mathematically in the context of $\Delta U = q + w$."

- "Using atomization energies and bond enthalpy values, Hess's Law can be applied to estimate standard enthalpies of formation (ΔH^0_f) for molecules in the gas phase and enthalpy changes for gas-phase reactions."

They then described two difficulties associated with their chosen topic using their KoSc.

- "Reliant upon multiple 'little steps' to be done correctly which allows for more opportunities for error if not careful with attention to detail."
- "Being able to recognize how changing one thing can affect other things. For example, anticipating how manipulating one equation will require the manipulation of another equation in order to achieve the desired result. This can be cognitively demanding if not fully understood."

When discussing their teaching procedures, Taylor provided an example problem that demonstrated their KoSc.

- "For example, we may be interested in knowing the enthalpy change for the decomposition of $NaHCO_3$. Given that this is difficult to do empirically with the equipment available to us, I may have them determine the enthalpies of other intermediate reactions that can still provide the answer. Reactions that would apply to this and still be simple to perform and gather data for would be:

  $NaHCO_3$ (s) + HCl (aq) → NaCl (aq) + H_2O (l) + CO_2 (g)

  Na_2CO_3 (s) + 2HCl (aq) → 2NaCl (aq) + H_2O (l) + CO_2 (g)"

<u>Summary of KoSc</u>

In their CoRe, Taylor detailed their knowledge of Hess's law and other chemistry concepts. The main themes for KoSc were:

- Taylor was able to share in-depth knowledge of advanced chemistry concepts, while also adapting the concepts to the high school level. Their expression of their KoSc indicated improvements to their PCK.
- Taylor analyzed the difficulties associated with teaching their chosen topic, which demonstrated further KoSc and KoT development and revealed improvements to the quality of their overall PCK.

KoG

The next code for the CoRe assignment relates to KoG, which may include learning goals for scientific literacy, real-life application, and integrated understanding.[41] Taylor described the importance of learning Hess's Law. The bolding in the statement below was original to the participant's response.

- "I think one of the most important reasons for students to know this is because Hess's Law is a wonderful example of the **law of conservation of energy**. Conservation of energy is a multidisciplinary idea and being able to transfer an understanding of it to other content areas can help make understanding those areas a bit more likely to occur. Additionally, students in high school get little experience with even the most basic thermodynamic principles. Taking time to understand concepts like the 1st Law, system vs surroundings, and what it means to be a state function can do a lot for their understanding of energy, overall."

Taylor was able to assess how their chosen concept connects to other thermodynamics topics and would better support students' understanding of energy. They also shared their KoCO by discussing the lack of emphasis on thermodynamics in the high school chemistry curriculum. By combining their KoCO and KoG, Taylor demonstrated improvements to the quality of their PCK.

KoSt

The next code is KoSt, which focuses on different learning levels, needs, interests, prior knowledge, ability, learning difficulties, and misconceptions.[41] Taylor chose to teach their topic in an 11th grade general chemistry course. When discussing their topic choice, two of Taylor's statements related to students' prior knowledge, which reveals their KoSt.

- "Lack of student background knowledge and with heat energy. Though students would have certainly dealt with energy in the past, it would have only been at a very concrete level with little analysis of the transfer of heat energy, calculations, and directionality of heat. They most definitely would not have had experience with enthalpy."
- "Use of fractions within the balanced chemical equation. By the time students would be taught this concept, they would be so used to the idea of integers being the only things allowed within a chemical equation that it would be a completely foreign idea to them. The potential for a complete lack of understanding of the purpose for why we might need to use fractions sometimes would be very high."

Similarly, Taylor addressed students' prior knowledge when discussing difficulties or limitations associated with teaching Hess's law.

- "Wide variation in mathematical background and ability."

- "Communicating the directionality (+/-) of heat. Students have little to no prior experience attaching +/- signs to heat and the connection to ideas of endothermic and exothermic processes."

Taylor also demonstrated their KoSt by sharing their observations of students' thinking or behavior in the past. Taylor was able to provide examples of student difficulties and assess potential challenges students may face during their CoRe lesson.

- "As novice chemistry students, they are susceptible to not recognizing the impact of how failing to do 'this step' or forgetting 'this detail' has on the overall answer to the problem. Chemistry teachers see this all the time even with basic processes such as calculating molar mass. Students forget about or misapply a subscript here and there or use the wrong molar mass of an element. Though their calculator provides them with an answer, they don't take the time to just quickly re-check their work to see if their answer makes sense."
- "Being able to recognize what kinds of changes need to be made to intermediate reactions involves a kind of hypothetical-deductive reasoning that will be inherently difficult for many students. Overcoming this specific barrier will almost certainly require some kind of scaffolding."

When discussing the factors that influence their teaching of Hess's law, Taylor discussed the mathematics involved with the topic. They anticipated the challenges this may pose for students, which revealed their KoSt.

- "The involvement of fractions as coefficients within chemical equations will be something completely foreign to them and will feel like we are breaking some kind of important rule. I would anticipate some students not seeing the rationale for why it makes sense in this context to utilize fractions in this way. Additionally, the struggle with fractions could become apparent when changes are made to chemical equations involving fractions. For example, if it is determined that a chemical equation need to be multiplied by 3, and there is a ½ coefficient present, I would anticipate some students struggling to properly realize that the coefficient should now change to 3/2."

Summary of KoSt

In their CoRe, Taylor was able to detail their KoSt by discussing challenges students may face when learning Hess's law. The main themes for KoSt were:

- Taylor was aware of their students' level of prior knowledge and planned to adapt their instruction to best suit students' needs. Connecting to their KoT, Taylor discussed the need for scaffolding to make their chosen topic accessible for their students. This combination of KoSt, KoSc, and KoT reveals improvements to the quality of their PCK.
- Taylor was able to utilize their past KoSt to develop a CoRe lesson that anticipated difficulties students may face during instruction. This allowed for more effective teaching and improved PCK.

KoCO

The next code relates to KoCO, which may relate to state and local standards.[41] Taylor provided a relevant state standard, noting: "in the new [state] science standards that will be implemented starting in 2023, this standard most closely relates to this concept." Throughout the CoRe, Taylor made decisions about what to teach depending on their KoSt and KoCO, demonstrating improvements to the quality of their PCK.

KoT

The next code is KoT, which involves the discussion of teaching methods and activities.[41] First, Taylor was asked to share the teaching procedures related to their chosen lesson. For their CoRe lesson, they included the "use of diagrammatic models," "Think-Pair-Share" discussions, and "opportunities to apply Hess's Law based on empirical evidence." The reasoning behind Taylor's choice of teaching procedures is given below.

- The "use of diagrammatic models to help them visualize the process of Hess's Law."
- "Understanding what changes need to be made to intermediate reactions can be a cognitively demanding task. Therefore, when attempting to practice this skill, I would ask individual students to write down the steps of the changes they would make that would result in the primary equation. Such steps would include things like: 'Flip equation 1, double equation 2, or flip and ½ equation 3.' Then, students would pair up and share their approaches to check for similarities and/or differences."
- "Giving them opportunities to validate a concept not only allows them to apply the skills needed but it also gives a sense of purpose and credibility to what we're learning about."

Taylor discussed scaffolding in greater depth, within the context of their CoRe lesson on Hess's Law. This statement connects their KoSc, KoT, and KoSt, which demonstrates improved PCK quality.

- "Finding various ways to introduce and apply scaffolds for students will be necessary; especially at the beginning. This could include anything from providing a defined space for them to write down their thinking for each step made along the way or reducing the options for potential changes that could be made to the intermediate reactions (ex: 'flip equation 1 OR multiply equation 1 by 2')."

Summary of KoT

In their CoRe lesson plan on Hess's Law, Taylor discussed their teaching procedures. The main themes for KoT were:

- Taylor included multiple teaching strategies for their CoRe lesson, showing their KoT through their awareness of the value of differentiated instruction. This demonstrated improvements to their PCK.
- Taylor was able to discuss the purpose of their instructional choices, touching on how their KoSt, KoT, and KoSc impacts their teaching. This intertwining of knowledge bases revealed improvements to the quality of their PCK.
- Taylor's mention of scaffolding combines their KoSt and KoT, which demonstrates improved PCK quality, and reveals student-focused motivations for their teaching.

KoA

The next code is KoA, which details teachers' knowledge of formal and informal assessments and feedback.[41] In Taylor's discussion of their teaching procedures, they outlined "applicable assessment opportunities":

- “Instead of solely relying on traditional Hess’s Law problems, incorporate problems that relate directly back to lab experiences, like the one mentioned above. Doing so can avoid students falling into a purely algorithmic way of thinking that lacks a deeper understanding.”

Taylor then described how they would assess student understanding or confusion. They detailed group discussion and modeling that would allow students to communicate their reasoning and expose any misconceptions. This combination of their KoA and KoSt demonstrated improvements to their PCK quality.

- “Based on problem assigned, groups are tasked with clearly laying out their thought process for changes made to intermediate reactions and how it contributes to the overall determination of enthalpy change for the reaction. Groups could be asked to communicate this using some kind of diagrammatic model like the one included above. Once finished, groups could present their reasoning to the class, where they will need to justify how their decisions result in the net reaction being the same as the primary reaction. Alternatively, whiteboards can be displayed throughout the room and students can walk by each one and provide feedback for original group to think about. Whiteboarding their ideas will naturally bring out misconceptions such as not properly changing intermediate reaction in such a way that terms cancel or not recognizing the need for changing the enthalpy value to reflect the change in made to its equation. Such misconceptions can be addressed openly and discussed with the class.”

Taylor also discussed working through incorrect responses to problems for students to practice problem-solving skills.

- "Presenting them with problems that I have answered INCORRECTLY, and they need to evaluate where I went wrong along. Evaluation of ideas and recognizing what is correct and incorrect is an essential skill for a deeper understanding to be developed."

Summary of KoA

Taylor shared multiple methods of informal assessment that they would use when teaching their CoRe lesson. The main themes for KoA were:

- For Taylor, assessing student understanding involved students' active involvement in applying their knowledge. Their combined KoA, KoT, KoG, and KoSt revealed improvements to the quality of their overall PCK.
- Taylor included multiple assessment methods, showing variation in their KoA and indicating improvements to their PCK.
- Taylor used assessment methods that would expose student misconceptions so they could be addressed, which combines their KoA and KoSt and demonstrates improved PCK quality.

KoR

The final code in Codebook 2 relates to KoR, which discusses materials and activities that teachers utilize in their classrooms.[41] Taylor shared their KoR by discussing the use of models and addressing a lack of equipment for measuring enthalpy changes.

- "Given that this is difficult to do empirically with the equipment available to us, I may have them determine the enthalpies of other intermediate reactions that can still provide the answer."

Taylor exhibited their KoR by describing multiple resources that would be used during their instruction of a CHEM 772 topic.

Summary of CoRe Data

Taylor's CoRe lesson over Hess's Law brought together the content knowledge they gained in CHEM 772 (KoSc) and their KoSt and applied these knowledge bases to their teaching (KoT). This combination of knowledge bases indicated improved PCK quality. The main themes for Taylor's Spring 2022 CoRe were:

- Taylor shared their content knowledge gained in the CHEM 772 course (KoSc) by applying it to a teaching situation (KoT). They involved their KoSt by taking into account students' prior knowledge and shared assessment methods that would best fit the learning that takes place in their classroom (KoA). This combination of knowledge bases revealed the presence of Taylor's PCK. Many of their responses intertwined multiple PCK bases, showing improvements to the quality of their PCK due to their engagement with the CoRe module assignment.
- Taylor planned their CoRe lesson with student misconceptions and learning difficulties in mind, paying special attention to the challenges inherent to the content. This demonstrated Taylor's reflection on how their chosen thermodynamics topic could be best adapted to their teaching context. This combined Taylor's KoSt, KoSc, and KoT, thus demonstrating improvements to the quality of their PCK.
- Taylor's goals (KoG), teaching choices (KoCO), and teaching procedures (KoT) aligned by creating a lesson that showcased the interconnectedness of

thermodynamics concepts. This combination of knowledge bases demonstrated improvements to their PCK quality.

Module Survey – CoRe

After completing the CoRe assignment, Taylor was invited to complete a survey about their experience creating a CoRe for their topic. The CoRe module survey was coded using Codebooks 1, 3, and 4.

Codebook 1

Coding frequencies for Codebook 1 can be found in Table 46.

Table 46. Module Survey Coding Frequencies for Semester 2 CoRe – CB1

Code	**Abbreviation**	**Frequency of Responses (*N* = 11)**	**Percentage of Total Responses (%)**
Attitudes	A-c	2	18.2
Knowledge	K-c	2	18.2
Teaching	T	3	27.3
Feedback	F	1	9.1
Reflection	R	3	27.3

Attitudes (A-c)

When describing their attitudes, Taylor discussed improved teaching confidence due to creating a CoRe for a challenging concept.

- “Since it's such a reflective exercise, it's hard not to come away with a greater sense of confidence in how I might be able to teach this concept.

When asked about their confidence level on a scale of 1 to 6 for teaching their concept, Taylor responded with a score of 5.

Knowledge (K-c)

Taylor described how the CHEM 772 course helped them gain a stronger content understanding of thermodynamics. This improvement to their KoSc demonstrated improved PCK.

- The CHEM 772 course has "helped provide me with a much more comprehensive (and deeper) understanding of thermochemistry. More specifically, engaging in the discussions related to solving problems, like the bond enthalpy problem the other week, has helped me understand the various misconceptions that can arise when doing problems like this."

Taylor demonstrated improved PCK quality by discussing their content knowledge (KoSc) in terms of their ability to teach the content (KoT).

- "I feel like I understand it as well as I need to in order to teach it effectively."

Teaching (T)

Taylor shared their reasoning for not feeling comfortable teaching their chosen thermodynamics topic without preparing beforehand. This discussion of their KoT and KoSt demonstrated improvements to their PCK quality.

- "Due to the degree of difficulty I would anticipate my students having, I would want to ensure some kind of scaffolds are created and in place. This topic will not be effectively understood if I don't have examples ready to go and haven't taken the time to anticipate potential misconceptions arising from those examples that I should be on the lookout for."

Due to their strong content understanding (KoSc), Taylor described their ability to teach the concept effectively (KoT). This combination of knowledge bases demonstrated improvements to their PCK quality.

- "I can create and solve problems, identify mistakes, anticipate misconceptions, and provide the necessary reasoning throughout teaching this concept."

Creating a CoRe for Hess's Law helped Taylor further develop their KoA and KoT, which indicated improvements to their PCK.

- The CoRe has "helped me realize different ways in which I could assess this concept as well as increase the variety of ways that I provide practice opportunities for my students with this concept."

Feedback (F)

Taylor shared one comment coded as feedback. This statement was further analyzed using Codebook 3, which will be shared in the section below.

Reflection (R)

Taylor described the amount of reflection that occurred when they were preparing a CoRe for a thermodynamics concept.

- The CoRe "involved a decent amount of reflection on the topic and how teaching it might unfold in my classroom. Doing this kind of reflection can be demanding but I wouldn't consider it to be challenging."
- "It's such a reflective exercise."

Codebook 3

Taylor shared one comment coded as "Feedback." This statement was further analyzed using Codebook 3. These coding frequencies are shown in Table 47 below.

Table 47. Module Survey Coding Frequencies for Semester 2 CoRe – CB3

Code	**Abbreviation**	**Frequency of Responses (*N* = 1)**	**Percentage of Total Responses (%)**
Assignment Feedback	AF	1	100

<u>Assignment Feedback</u>

Taylor discussed the value of having discussions focused on problem solving in the CHEM 772 course.

- CHEM 772 "has helped provide me with a much more comprehensive (and deeper) understanding of thermochemistry. More specifically, engaging in the discussions related to solving problems, like the bond enthalpy problem the other week, has helped me understand the various misconceptions that can arise when doing problems like this."

<u>Codebook 4</u>

Codebook 4 was used to identify the source of motivation that fueled Taylor's comments. Coding frequencies can be found in Table 48.

Table 48. Module Survey Coding Frequencies for Semester 2 CoRe – CB4

Code	**Abbreviation**	**Frequency of Responses (N = 6)**	**Percentage of Total Responses (%)**
Learning-focused	L-f	1	16.7
Student-focused	S-f	2	33.3
Teaching-focused	T-f	3	50

Taylor included all sources of motivation in their responses to the CoRe module survey, including comments about their teaching ($N = 3$), their students' learning ($N = 2$), and their own learning ($N = 1$). An example of each code is given below.

- "I can create and solve problems, identify mistakes, anticipate misconceptions, and provide the necessary reasoning throughout teaching this concept." (T-f)
- "Due to the degree of difficulty I would anticipate my students having, I would want to ensure some kind of scaffolds are created and in place." (S-f)
- The CHEM 772 course has "helped provide me with a much more comprehensive (and deeper) understanding of thermochemistry." (L-f)

Summary of Module Survey - CoRe

When describing their experience completing a CoRe for a CHEM 772 topic, Taylor primarily gave statements related to their teaching and reflection. Codebook 4 revealed that half of their responses were motivated by their teaching, while fewer comments addressed implications for their students' learning (33.3%) and their own learning (16.7%). The main themes for Taylor's Spring 2022 CoRe module survey were:

- Reflecting on how they planned to teach thermodynamics topics increased Taylor's teaching confidence and allowed them to think about how they would assess student learning for this concept, which shows improvements to their KoT and KoA, as well as their overall PCK.
- Gaining chemistry content knowledge (KoSc) in the CHEM 772 course allowed Taylor to be able to teach more effectively by reflecting on potential student misconceptions and creating resources for their lesson, demonstrating KoT, KoSt, and KoR as components of PCK. This intertwining of knowledge bases demonstrates improvements to the quality of their overall PCK.
- Discussions in the CHEM 772 course focused on solving problems helped Taylor understand potential misconceptions, thus improving their KoSt and KoSc, which improved the quality of their overall PCK.

Check-in Interview 2

Near the end of Semester 2, I interviewed Taylor via Zoom to learn more about their experience in the MS program during Semester 2. The second check-in interview was coded using Codebooks 1, 3 and 4.

Codebook 1

Codebook 1 coding frequencies are shown in Table 49.

Table 49. Check-in Interview 2 Coding Frequencies – CB1

Code	**Abbreviation**	**Frequency of Responses (N = 22)**	**Percentage of Total Responses (%)**
Attitudes	A-c	1	4.5
Knowledge	K-c	1	4.5
Goals	G	1	4.5
Experience	E	4	18.2
Teaching	T	1	4.5
Feedback	F	7	31.8
Interaction	I	1	4.5
Reflection	R	6	27.3

Attitudes (A-c)

Taylor shared positive attitudes toward coming to SDSU for the two-week summer session.

- "I'm excited to come this summer."

Knowledge (K-c)

In terms of knowledge, Taylor expressed gaining knowledge (KoSc) through the CHEM 772 course, which demonstrated improved PCK.

- "I've been learning a lot more in Thermo (772) lately."

Goals (G)

Relating to the CHEM 778 course, Taylor discussed wanting to integrate new science teaching strategies from the course texts into their instruction. They shared a goal for implementing new techniques into their instruction by the fall semester. This discussion of their KoT and KoR indicated improvements to the quality of their PCK.

- “There's so much stuff in *Ambitious Science Teaching*[72] and in *Developing Creativity in the Classroom*[73], it's really worthwhile thinking about. I know some of these small group discussion techniques, I really, really want to start to incorporate more of from the *Ambitious Science Teaching*[72] book and having that conversation with my colleagues, so I really think that after having a summer to condense it and think about it and figure out how I'm going to put this into a more routine part of my room, then that's going to start to show up in the fall.”

Experience (E)

Taylor described their experience in the program during Semester 2. They first described an experience relating to their action research. Taylor related how they misunderstood an assignment and went above and beyond the expectations for the assignment, an accident that contradicted their previous experiences of feeling like they had procrastinated in prior courses.

- “I'm finding that a lot of times for the classes that involve papers, especially the one whose obvious objective is to help build your master’s research project – that's obviously going to be spread out over time – but it's very easy to do the cliché wait, wait, wait, wait, wait until it's a little bit too late. Interestingly, I accidentally submitted - well, Instructor B was asking for a small fraction of the beginning of your paper. Like what are some research questions and just some basic stuff, and I misinterpreted that as your full-blown intro, methods, lit review – everything. So I had spent maybe 12 hours total, essentially doing the whole thing. And I was like, ‘Oh God, I can finally breathe’ and I submitted it, and they’re like ‘this is really good and everything, but you only needed to do this much.’”

Taylor then shared their experience of brainstorming an idea for their action research project.

- “The essential question is basically: Does me as a teacher requiring you as a student to meet a particular threshold of understanding throughout a unit have an impact on your summative evaluation?”

They then went into a detailed explanation of how they would carry out an action research project to answer this question. After their explanation they discussed their experience of communicating their idea verbally versus through writing.

- “Sorry, that wasn't concise. I put everything together in a fluid way on the paper. But then trying to make sure that I can explain it in a much more clear way is still a work in progress.”

Later in the interview, Taylor discussed an experience in CHEM 778 that led them to create an activity resembling the demonstration done in the Zoom meeting. They used this experience as an example for how the course content made an impact on their teaching. This demonstrates the MS program’s impact on their KoT and KoR, which improved the quality of their overall PCK.

- "There was one Zoom session where Instructor A was trying to lead a discussion on anchoring phenomena, and they did a demo involving an acid and a base where they poured one into the other. It turned blue, and as they poured more of that liquid, it turned back to being clear. A few weeks later, I actually ended up maybe spending about a half hour in class doing that exact same thing, but then expanding on it and then asking [students] to model what they think occurred based on what they saw. There have been direct content specific things that have found their way into my class."

<u>Summary of Experience (E)</u>

In the second check-in interview, Taylor described their experiences in the MS program, including in courses and preparations for their action research project. The main themes for the experience code were:

- Taylor described a demonstration that was presented in the CHEM 778 course that made its way into their teaching, revealing a direct impact of MS program course content on its participants' instruction. This is an example of improved PCK quality through improved KoT and KoR that Taylor actively developed during the MS program and implemented into their teaching.
- Taylor shared their current idea for their action research project, mentioning their ability to describe their research idea more clearly through writing.
- Taylor shared an experience of their time management, a skill they hoped to develop during their time in the MS program, wherein they completed more of their research paper than necessary. As will be discussed in the feedback chapter, Taylor felt that this experience could have been avoided through communication.

Teaching (T)

Taylor reflected on the knowledge they gained in the CHEM 770 course and how it impacted their teaching of these topics. This combined their KoSc and KoT, indicating improvements to their PCK quality.

- "From CHEM 770, one of the ways in which I knew it was going to impact [their teaching] was once we got to the atom and atomic theory and stuff like that. And we're just going to start that after spring break. I'm talking about things like photoelectron spectroscopy, which I've never done at the high school level and seeing how it fits into the larger model of transitioning, say from this atomic model to that atomic model. From a content point of view, yes, I've chosen to cover certain things in a specific way that is directly the result of me knowing more stuff now. I have more knowledge now, and so I'm like, 'Oh, this is how it fits into that.' I always knew about the ultraviolet catastrophe with respect to Max Planck but didn't really know about it. And as I learn more, I was like, 'Oh, okay, I could actually use this in a way to create some activity where the kids look at the data and generate the evidence and analyze it in such a way to help us give evidence to this new idea of light and matter' and stuff like that."

Feedback (F)

Taylor shared seven comments coded as feedback. These statements were further analyzed using Codebook 3, which will be shared in the section below.

Interaction (I)

Taylor discussed interactions they had with their advisor for their action research project. They described feeling more connected to others in the MS program because of getting to know their advisor more personally in addition to research requirements.

- “I've liked establishing that personal connection with Instructor B in relation to my research, so that's been nice. I would have been cool with it had it been Instructor B or Instructor A. I think it would be easy to talk to either of them, but it's been really nice to go beyond just the research and learn little things, like social things, about somebody else to establish that bond. And so it's nice to be able to have that connection even on the Tuesday Zoom meetings. It's nice to have that social connection to others in the class beyond just the discussion.”

Reflection (R)

Taylor reflected on how their experience in the MS program had gone so far. They described their experience balancing their responsibilities in life in addition to the MS program.

- “Good. It's been good. It’s certainly been busy and gotten a lot busier. I'm trying to balance all of this stuff…so [misunderstanding the research paper assignment expectations] was a good example of how me trying to balance many plates not just in the grad school environment, but also teaching, family, and [coaching]. How something simple like that can get misunderstood.”

Other than the above issue with finding balance, they reflected that the MS program has been going well for them.

- "But yeah, things are going fine otherwise. There have been some - life has gotten in the way, and I just didn't get this particular discussion response done. And in the grand scheme of things, it's not something I lost sleep over or anything like that, but I'd say otherwise it's been going really well…I think it's been going well."

Taylor reflected on their participation in an MS program that they find more valuable compared to what they have heard from their colleagues about educational master's programs. They discussed the benefit of being in a program that is challenging, stating that the challenges would lead to better growth.

- "In talking to other teachers, whether they're science or not, about their master's programs, I'm really glad that I went. I'm in a program that is demanding and challenging…I was talking to a guy the other day and he was part of a master's program where literally in the middle of the program, they were going to stop becoming a college. And so therefore he was able to submit assignments that were really lazily written and stuff like that and still got full credit. And so there's always this part of you that's like 'God, I wish it was just easier and I could take the path of least resistance.' But then there's this larger part of me that's like, 'Yeah, but that's not good for me and what's best.' So I do actually really like the fact that it is challenging, even though challenging can be difficult."

Twice during the interview Taylor reflected that the MS program has given them opportunities to think about their pedagogical choices but that it has not yet made a tangible impact. However, they did experience improvements to their KoT – and overall PCK – even if they had not yet implemented this new knowledge into their instruction.

- "As far as pedagogy, it's tough because these are my first pedagogy classes this semester, so it's tough in the moment while I'm in step with those to be making some kind of transition. I think they've definitely given me stuff to think about."
- "I can't say right now from a pedagogy point of view that it's impacted directly how I go through my class. But it's definitely impacted how I think about what I intend to do in class. I'm just not quite there yet in a way that it's been able to piece it together."

Summary of Reflection (R)

When reflecting on their experience in their first two semesters in the MS program, Taylor's comments focused on the following themes:

- Finding balance has been a challenge between Taylor's obligations for the MS program in addition to their teaching and family life.
- Compared to other master's programs for education professionals, Taylor found the MS program to be challenging, yet worthwhile.
- Taylor stated that they have not yet been able to apply pedagogical knowledge from the MS courses to their teaching but reflected on the changes they intend to implement in the future. Although they improved their KoT and, thus, their PCK, this indicates that further PCK development may require additional time as participants reflect on knowledge they have gained through MS program courses.

Codebook 3

Taylor shared seven comments coded as "Feedback." These statements were further analyzed using Codebook 3. These coding frequencies are shown in Table 50 below.

Table 50. Check-in Interview 2 Coding Frequencies – CB3

Code	**Abbreviation**	**Frequency of Responses (N = 7)**	**Percentage of Total Responses (%)**
Course Delivery Feedback	CDF	3	42.9
Logistical Feedback	LF	4	57.1

Course Delivery Feedback

Taylor hoped for an online database of video lectures from MS program instructors, sharing that they have been teaching themselves or relying on the book often during CHEM 772.

- "I do wish there was [an online database of MS program lectures] because when I think about [CHEM 772], a lot of it has been teaching either myself or trying to rely on the book."

On the other hand, they appreciated the use of an online homework software in CHEM 772 that provided feedback.

- "I do like the OWL Cengage thing. I like the opportunity for practice on that and how it gives you feedback. That's been really helpful and that's something I hadn't experienced in any other classes prior to [CHEM 772]."

They appreciated the use of Zoom meetings in MS program courses.

- "I've liked the at least weekly Zoom sessions. I like that."

<u>Logistical Feedback</u>

Taylor discussed “the importance of communication in the digital environment” and gave positive feedback on weekly communication that has taken place in MS program courses.

- Misunderstanding research assignment guidelines “wasn't on Instructor B because it was 100% on me, but I'm just thinking more broadly the importance of communication in the digital environment as far as, ‘okay, here is what we are doing this week.’ I really do like how all the professors have said, ‘okay, week of April 1st, here are your things to do.’ That's actually what we've started to do at the high school level [during] COVID, but seeing it as a student, it does help.”

Taylor suggested having an online database of video lectures from MS program instructors.

- “Maybe this is an ‘in the future’ thing because I don't know how old the program's online presence is - but I wish there was an online database or something of lectures available for a variety of different things that were specific to the SDSU professors. I'm thinking back to CHEM 770, for example, where weekly Instructor A would upload those various talks and it's like those are made now, or maybe you make one that's ‘I'm going to use at least until I want to make a new one related to this topic.’”

Taylor shared positive feedback regarding MS program instructors’ communication but emphasized the need for uniformity across courses in terms of course organization, especially on the D2L site.

- "I've felt that the professors have always been very reachable, very in communication. It might differ in terms of how they do it, which is understandable. Having more uniformity, not in terms of teaching, but in terms of structural things for how a class is set up online [would be valuable]. For example, when I want to go to a discussion in 778, I click on 'Communications' and then I click on 'Discuss.' And then there's all these discussions. But when I go to a discussion in 772, if I do that exact same thing, there's nothing there, but the discussion itself is embedded within the content stuff. Is it a huge deal? No, but for somebody who isn't as knowledgeable of how to navigate an online scheme like that, it might be better" to have more uniformity.

Taylor appreciated having required Zoom sessions as an incentive to participate. They also discussed having Zoom sessions later in the week when they are more likely to need help.

- "I actually like that [the CHEM 778 Zoom sessions] are required because it requires me to really engage with it. 772 is optional. I've been to a couple, but it's also because earlier in the week I don't know that I need any help with 772. I don't go because I just don't know I need help."

Codebook 4

Codebook 4 was used to demonstrate the motivations behind Taylor's comments. These coding frequencies are shown in Table 51 below.

Table 51. Check-in Interview 2 Coding Frequencies – CB4

Code	**Abbreviation**	**Frequency of Responses (N = 12)**	**Percentage of Total Responses (%)**
Learning-focused	L-f	8	66.7
Teaching-focused	T-f	4	33.3

Taylor did not include any student-focused motivations in the second check-in interview. Most of Taylor's comments related to their own learning and professional development through the program (66.7%). One-third of Taylor's comments were motivated by their teaching.

Summary of Check-in Interview 2

During the second check-in interview, Taylor reflected on their experience in the MS program in their second semester and overall, progress they have made toward determining the focus of their action research project, and any changes they have made to their teaching so far. Taylors comments during the interview primarily focused on their teaching (66.7%) but were also motivated by their own learning that took place during the MS program (33.3%). The main themes from Check-in Interview 2 were:

- Although Taylor discussed not incorporating new pedagogical techniques into their teaching yet, they shared their intentions to change their teaching due to what they have learned in CHEM 778. These teaching changes would indicate further improvements to their PCK due to the MS program. However, the knowledge and skills they gained through CHEM 778 demonstrated improved KoT and, thus, improved PCK.

- During Semester 2, Taylor described being able to teach topics in greater depth, or introduce new topics, due to the CHEM 770 course. This demonstrates the intertwining of their KoSc and KoT, which indicates improved quality of their overall PCK. Taylor showcased a direct positive impact of MS program content courses on a participant's teaching effectiveness.
- Taylor discussed progress to their development of an action research project, including meaningful interactions they have had with MS program faculty.
- Taylor discussed their need to find balance between graduate school, teaching, family, and coaching.
- Based on conversations they had with colleagues, Taylor felt confident that the MS program was more challenging and effects more valuable learning than other master's programs for educators.
- Taylor gave positive feedback regarding the use of an online homework program in CHEM 772, the weekly Zoom meetings, weekly communication, and the accessibility of the MS program instructors.
- Taylor hoped for more uniformity across courses, especially in terms of online course organization. They also hoped for an online database of video lectures from MS program instructors.

Midway Course Reflection (CHEM 778)

The midway course reflection asked participants to think about what they had gained pedagogically through CHEM 778: Chemistry Teaching Strategies. Taylor's responses to the Midway Course Reflection were coded using Codebooks 1, 2, and 4.

Codebook 1

Coding frequencies for Codebook 1 can be found in Table 52.

Table 52. Midway Course Reflection Coding Frequencies – CB1

Code	**Abbreviation**	**Frequency of Responses (*N* = 15)**	**Percentage of Total Responses (%)**
Attitudes	A-c	1	6.7
Skill	S-p	1	6.7
	S-c	1	6.7
Teaching	T	5	33.3
Background	B	1	6.7
Experience	E	1	6.7
Reflection	R	5	33.3

Attitudes (A-c)

In the Midway Course Reflection, Taylor described how the CHEM 778 course inspired them to incorporate new pedagogical strategies into their instruction. Their gain of chemistry teaching strategies indicated improved KoT and, thus, improved PCK. They also shared their positive attitudes toward reflecting on the course during the summer to determine how they would implement these new ideas.

- "Ultimately, this class has produced one of those feelings where I want to incorporate SO much of what I've learned but haven't fully had the time to process exactly how I want to go about integrating it into my classroom. I'm actually really looking forward to the summer since it will provide me with that necessary reflective time to make next year even better."

Skill (S-p and S-c)

In terms of pedagogical skill, Taylor discussed their discussion facilitation techniques (KoT) prior to taking the CHEM 778 course, which described their baseline PCK.

- "Based on my early training in Modeling Instruction…I've always felt like I've had a natural ability to guide class discussions with a Socratic-type of feel that can encourage students to develop and apply their thinking skills within a given topic. However, I've always felt that I rely too heavily on sort of just 'winging' the facilitation of class discussions because it feels natural to me."

After participating in the course, Taylor discussed how they were now able to include structure in their discussion techniques, as well as necessary scaffolding. This improvement to their KoT demonstrated improved PCK.

- "Many of the topics we've covered throughout this book have helped provide me with the necessary structure that I've been lacking in my discussion techniques. This includes such things being introduced to scaffolds that I can provide my students with to help them think about the concepts we will be discussing in class."

<u>Teaching (T)</u>

Since CHEM 778 was a chemistry teaching strategies course, many comments from Taylor's Midway Course Reflection related to their teaching. Taylor discussed how the CHEM 778 course content had impacted their teaching. These improvements to their KoT demonstrated improved PCK. Some statements related to general course takeaways.

- "Ultimately, I would say that the biggest impact this class has had on my teaching is the incorporation of STRUCTURE to aspects of teaching that don't naturally have a one-size-fits-all template."
- "One of ideas that I've already began to utilize since starting this course is the incorporation of phenomena to hook student interest, encourage discussion and provide a sense of purpose for why we are learning about a given topic."
- "The ideas surrounding creativity we've been learning about have really opened up a new set of ideas in my teaching. It's forced me to realize that I need to be OK with giving my students more opportunities to expand on their own thoughts and approach representing concepts in new ways via models and explanatory scaffolds."

Other comments related to how Taylor actively changed their teaching due to what they had learned in the CHEM 778 course. These improvements to Taylor's KoT and KoR indicated improvements to their PCK quality.

- "A couple weeks after I saw [a demo in CHEM 778], I created an entire activity based on this simple demo that ended up producing a very useful class discussion involving acids, bases, pH, and particle-level models that ended up taking nearly the entire period to complete."

- "The 'sharing project' has also been a really useful addition to my own classroom. It's helped me take a lab that I've always enjoyed doing and expand on it in ways that have allowed my students to think more deeply about titrations, measurement, precision, and sources of error. It's been really interesting to spend time talking back and forth with my partner on how we can create opportunities for our students to engage with data generated from each of our respective schools."

Summary of Teaching (T)

One-third of Taylor's responses to the Midway Course Reflection focused on how their teaching had been or would be impacted by the CHEM 778 course content. The main themes for teaching were:

- The CHEM 778 course prompted Taylor to reflect on their current teaching and think about how they would teach science creatively and with structure. Increasing their KoT leads to increased PCK.
- Taylor described how they have actively made changes to their teaching, including new teaching strategies and activities, which demonstrates the direct impact of the CHEM 778 course on participants' teaching. Their comments also signify improved PCK quality through increased KoT and KoR.

Background (B)

As of Spring 2022, Taylor described their background with the following statement:

- "I began teaching nearly 10 years ago."

Experience (E)

Taylor detailed their experience in the program by describing a moment in the CHEM 778 course when their instructor performed a demonstration.

- "An example of [incorporating phenomena] was when Instructor A did the acid-base demo involving thymolphthalein and the clear to blue to clear color change that occurred when they mixed the solutions."

Reflection (R)

One-third of Taylor's comments were reflective. Some of their statements reflected on knowledge and ideas they had taken away from the CHEM 778 course to implement in their teaching. Their combination of KoT and KoR demonstrated improvements to the quality of their PCK.

- "The AST book that we've been discussing weekly has given me so much to think about that it's been almost impossible not to reflect on my current daily classroom practices. Though this specific book has covered a variety of topics, the ones that have impacted me the most are focused around questioning techniques, facilitating group discussions, and helping students generate and refine their models."
- "This demo instantly caught my attention and I immediately decided it would be great to do in my own classroom."
- "Though this was just one example, there have been other ideas we've learned about that have inspired to me to slow down in my teaching and allocate more time to doing things like developing particle-level models and encouraging more small-group discussions to take place."

Relating also to their current attitude toward the course content, Taylor discussed their desire to reflect on what they gained from the CHEM 778 course in terms of changes they plan to make in their classroom. Their development of KoT indicates improved PCK, with further improvements possible after full reflection on the CHEM 778 course.

- "Ultimately, this class has produced one of those feelings where I want to incorporate SO much of what I've learned but haven't fully had the time to process exactly how I want to go about integrating it into my classroom. I'm actually really looking forward to the summer since it will provide me with that necessary reflective time to make next year even better.

Taylor also used the Midway Course Reflection to reflect on their teaching practices and identifying changes they want to make with the skills they developed in the CHEM 778 course. They shared how their teaching philosophy informs their teaching, which combines their KoG, KoSt, and KoT and reflects higher quality PCK.

- "The problem with ['winging' the facilitation of class discussions] is that it lacks the necessary structure to ensure all students have an opportunity to be heard and make the most out of participating in the development of concepts."

<u>Summary of Reflection (R)</u>

Given its name, the Midway Course Reflection gave teachers the opportunity to reflect on their experience in the CHEM 778 course. The main themes from Taylor's responses were:

- The knowledge, skills, and resources presented in the CHEM 778 course prompted Taylor to reflect on their current teaching practices and consider how they could bring these ideas into their own teaching. The CHEM 778 course increased Taylor's KoT, KoG, and KoR by allowing them to reflect on how and why they teach. This intertwining of knowledge bases indicates improvements to the quality of their overall PCK.

- By reflecting on the CHEM 778 course content and their current teaching practices, Taylor would be able to implement changes to their instruction. This reveals Taylor's desire to improve their teaching from their increased KoT, which indicated improvements to their PCK.

Codebook 2

Codebook 2 was used to analyze Taylor's demonstration of PCK in the Midway Course Reflection. Coding frequencies can be found in Table 53.

Table 53. Midway Course Reflection Coding Frequencies – CB2

Code	**Abbreviation**	**Frequency of Responses (*N* = 12)**	**Percentage of Total Responses (%)**
Knowledge of science	KoSc	1	8.3
Knowledge of goals	KoG	2	16.7
Knowledge of teaching	KoT	7	58.3
Knowledge of resources	KoR	2	16.7

Most of Taylor's comments about the CHEM 778 course reflected their KoT. Their responses also involved their KoG, KoR, and KoSc. An example of each knowledge base is given below.

- "The ideas surrounding creativity we've been learning about have really opened up a new set of ideas in my teaching." (KoT)
- "The problem with this is that it lacks the necessary structure to ensure all students have an opportunity to be heard and make the most out of participating in the development of concepts." (KoG)
- "A couple weeks after I saw it, I created an entire activity based on this simple demo." (KoR)
- "An example of this was when Instructor A did the acid-base demo involving thymolphthalein and the clear to blue to clear color change that occurred when they mixed the solutions." (KoSc)

These improvements to individual knowledge bases indicate improvements to their overall PCK.

Codebook 4

Codebook 4 was used to identify the source of motivation that fueled Taylor's comments. Coding frequencies can be found in Table 54.

Table 54. Midway Course Reflection Coding Frequencies – CB4

Code	Abbreviation	Frequency of Responses ($N = 18$)	Percentage of Total Responses (%)
Learning-focused	L-f	4	22.2
Student-focused	S-f	4	22.2
Teaching-focused	T-f	10	55.6

When reflecting on what they had gained from the CHEM 778 course, Taylor focused most of their comments on how new ideas have impacted their teaching (55.6%). Their remaining comments were motivated by their learning (22.2%) and the course's impacts on their students' learning (22.2%). An example of each motivation is given below.

- "Ultimately, I would say that the biggest impact this class has had on my teaching is the incorporation of STRUCTURE to aspects of teaching that don't naturally have a one-size-fits-all template." (T-f)
- "Ultimately, this class has produced one of those feelings where I want to incorporate SO much of what I've learned." (L-f)
- "It's helped me take a lab that I've always enjoyed doing and expand on it in ways that have allowed my students to think more deeply about titrations, measurement, precision, and sources of error." (S-f)

Summary of Midway Course Reflection

The Midway Course Reflection gave Taylor an opportunity to reflect on what they had gained from the CHEM 778: Chemistry Teaching Strategies course. The main themes were:

- Based on the pedagogical skill and knowledge they had gained in the CHEM 778 course, Taylor felt a desire to reflect on their current teaching and implement new ideas into their instruction, demonstrating a direct impact of the MS program on its participants' teaching (KoT) and, therefore, their PCK.
- By discussing how they have actively made changes to their teaching, including new teaching strategies and activities, Taylor demonstrated improved PCK through increased KoT and KoR.
- In their responses to the Midway Course Reflection, Taylor practiced and demonstrated their KoT, KoR, KoG, and KoSc, which demonstrated growth in their PCK, as well as improvements to the quality of their PCK when these knowledge bases were combined.
- Taylor's responses to the Midway Course Reflection demonstrated their motivations to improve their teaching through their experience in the MS program, as well as improve their own students' learning experiences. They combined their KoG, KoSt, and KoT, which indicated improvements to the quality of their PCK. Taylor also demonstrated knowledge and skills that they personally gained from the CHEM 778 course.

Teaching Observation 2

Pre-Observation Survey

Upon scheduling the Zoom teaching observation, I sent the pre-observation survey to Taylor by email to complete prior to the observation. The pre-observation survey was coded using Codebooks 1, 2, and 4.

Codebook 1

Codebook 1 coding frequencies are shown in Table 55.

Table 55. Pre-Observation Survey Coding Frequencies for Observation 2 – CB1

Code	**Abbreviation**	**Frequency of Responses (*N* = 9)**	**Percentage of Total Responses (%)**
Attitudes	A-c	3	33.3
Knowledge	K-c	1	11.1
Skill	S-c	1	11.1
Teaching	T	4	44.4

Attitudes (A-c)

When discussing how they feel about their observed lesson, they said “I feel good about it.” Taylor shared their attitudes toward their students’ ability to understand the content. By demonstrating their KoSt, they revealed their PCK.

- “When it comes to electron configuration, they will do just fine. I have no concerns about this.”

When asked if they feel confident teaching this lesson, they said “absolutely, yes,” and attributed this to their experience in the CHEM 770 course.

- “To be honest, I feel MUCH more confident after taking CHEM 770 – Atomic Theory.”

<u>Knowledge (K-c) and Skill (S-c)</u>

Due to improvements to their KoSc in the CHEM 770 course, their pedagogical skill improved, demonstrating increased PCK.

- “Since I feel like I understand [the content] so much better, I can explain it better and make a variety of different connections in ways that I may not have been able to previously.”

<u>Teaching (T)</u>

Taylor chose to teach “electron configuration and the quantum atomic model” for their observed lesson, which demonstrated their KoCO as a component of their PCK.

- “It’s a bit more direct instruction than I like to do but we recently did an inquiry-based activity and certain gaps in understanding need to be filled in.”

When describing changes they made to their lesson, they discussed added content and described their reasoning for including new concepts. This indicated that they applied KoSc gained in the MS program to their teaching. This combination of KoSc and KoCO demonstrated improvements to their PCK quality.

- “More about wave-particle duality and the seemingly odd behavior of electrons. Part of this is because it’s super fun to talk about but a better reason is because of the importance of concepts like wave-particle duality in relation to the rationale for the quantum model.”

They also hoped the lesson would prompt discussion from their students.

- "Hopefully, it may spark some interesting questions, but we'll see."

Codebook 2

Codebook 2 coding frequencies can be found in Table 56.

Table 56. Pre-Observation Survey Coding Frequencies for Observation 2 – CB2

Code	**Abbreviation**	**Frequency of Responses (N = 10)**	**Percentage of Total Responses (%)**
Knowledge of science	KoSc	1	10
Knowledge of goals	KoG	2	20
Knowledge of students	KoSt	1	10
Knowledge of curriculum organization	KoCO	2	20
Knowledge of teaching	KoT	4	40

Taylor demonstrated the higher quality of their PCK by combining multiple knowledge bases. They described applying new content knowledge from CHEM 770 to their teaching, connecting their KoSc and KoT. They also reflected on their goals for student learning and anticipated student reactions to the content, which touched on their

KoG and KoSt. By discussing their teaching choices regarding content, they demonstrated their KoCO.

Codebook 4

Codebook 4 was used to demonstrate the motivations behind the teacher's comments. These coding frequencies are shown in Table 57 below.

Table 57. Pre-Observation Survey Coding Frequencies for Observation 2 – CB4

Code	Abbreviation	Frequency of Responses (N = 7)	Percentage of Total Responses (%)
Learning-focused	L-f	1	14.3
Student-focused	S-f	1	14.3
Teaching-focused	T-f	5	71.4

Taylor primarily included teaching-focused motivations when describing their observed lesson (71.4%), but also included comments motivated by their own learning (14.3%) and their students' learning (14.3%).

Teaching Observation

All teaching observations were conducted via Zoom. During Taylor's second semester in the program, I conducted their second teaching observation to assess their current level of teaching effectiveness and active PCK due to any program impact. During the observation, I took notes guided by the Instruction domain of the Danielson

Framework for Teaching Evaluation Instrument.[62] The notes of the teaching observation were then analyzed using Codebook 2. Codebook 2 coding frequencies can be found in Table 58.

Table 58. Observation 2 Coding Frequencies – CB2

Code	**Abbreviation**	**Frequency of Responses (N = 24)**	**Percentage of Total Responses (%)**
Knowledge of goals	KoG	4	16.7
Knowledge of curriculum organization	KoCO	3	12.5
Knowledge of teaching	KoT	8	33.3
Knowledge of assessment	KoA	8	33.3
Knowledge of resources	KoR	1	4.2

KoG

During their observed lesson, Taylor made multiple connections between the content and real-world examples. They also made connections to related chemistry concepts.

KoCO

Relating to their KoCO, Taylor connected their current lesson back to previous lessons by asking students to recall information learned previously in the course.

KoT

Taylor used a simulation for the double-slit experiment to support their instruction. When students seemed not to understand the concept from the simulation, they drew a model on board, checked multiple times for understanding, and asked if a different explanation was needed. Throughout the lesson, Taylor encouraged students to share their observations and ask questions. They communicated how they would like students to work through practice problems. When introducing a new concept, they included explanations from multiple angles to teach the topic in different ways. They involved multiple students in problem-solving and discussion, demonstrating their inclusion of students in their teaching approach.

KoA

Throughout the lesson, Taylor checked for understanding in a respectful manner. They cold called students to participate during discussions and involved multiple students when working through example practice problems. After going over example problems with support, they gave additional problems for students to work through in groups while Taylor circulated the room. When students presented ideas during discussion, they asked students for further elaboration of their thoughts. When using the simulation, Taylor prompted students with questions like “what if I do this?” or “what if I change this?” and invited students to share their understanding of the concept through discussion.

KoR

Taylor demonstrated their KoR by using a simulation for the double-slit experiment to support their instruction.

Post-Observation Survey

Once I was notified that the Zoom observation was complete, I sent Taylor the post-observation survey by email. The post-observation survey was coded using Codebooks 1, 2, and 4.

Codebook 1

Codebook 1 coding frequencies are shown in Table 59.

Table 59. Post-Observation Survey Coding Frequencies for Observation 2 – CB1

Code	**Abbreviation**	**Frequency of Responses (*N* = 6)**	**Percentage of Total Responses (%)**
Attitudes	A-c	1	16.7
Teaching	T	3	50
Reflection	R	2	33.3

Attitudes (A-c)

Taylor was asked to explain their degree of confidence in relation to the learning that took place during their lesson. They demonstrated their KoSt as a component of their PCK.

- "I'm confident they learned about the electron configuration aspect of the lesson."

They provided their reasoning behind their confidence by using their KoA, which is discussed below in the Codebook 2 analysis.

Teaching (T)

Taylor discussed what occurred during the teaching of their observed lesson and explained how they will move forward with their instruction in future class periods.

- "Students were able end class with seeing how we draw a quantum model so that by the time they come to class today, we can use that topic as a natural point to jump off from."

Reflection (R)

In the post-observation survey, Taylor reflected on how their lesson went.

- "Though I didn't have a specific point that I wanted to reach, I was more than fine with ending at the point that we did."

When asked if they would repeat the lesson in the same way in future, Taylor said they would for "the electron configuration part," but explained their reasoning for removing the double-slit experiment component in the future. This related to their KoCO and KoT, which demonstrated improved PCK quality.

- "As fun as it is to talk about, I would likely remove the double-slit experiment part from this specific lesson and find a time later to on to discuss. It's not obvious the connection between the two different concepts discussed yesterday and would be better to separate at first."

Codebook 2

Codebook 2 coding frequencies can be found in Table 60.

Table 60. Post-Observation Survey Coding Frequencies for Observation 2 – CB2

Code	**Abbreviation**	**Frequency of Responses (*N* = 11)**	**Percentage of Total Responses (%)**
Knowledge of students	KoSt	3	27.3
Knowledge of curriculum organization	KoCO	1	9.1
Knowledge of teaching	KoT	4	36.4
Knowledge of assessment	KoA	3	27.3

In the post-observation survey, Taylor exhibited multiple components of PCK. When reflecting on their lesson, Taylor discussed their current teaching choices and changes they plan to make to the lesson in the future. Taylor demonstrated their KoSt, KoT, and KoA by reflecting on how their observed lesson went, which revealed their PCK. The statements below reflect Taylor's KoSt and KoA as they detailed their method of assessing student understanding or confusion. They combined these two knowledge bases, which indicated higher quality PCK. They first discussed how they know student learning took place due to their informal assessment in the form of direct questioning.

- "Electron configuration stuff—yes. I know this based on informal evidence gathered throughout the lesson… Through various questioning opportunities, I was able to get nearly every single student to provide a response. Nearly every response was correct, indicating that there was a collective sense of understanding."

Taylor also used their KoSt, KoA, and KoT to describe any potential misconceptions of the double-slit experiment and electron configuration topics. This intertwining of knowledge bases indicated improved PCK quality.

- "The double-slit stuff—yes. However, that's likely to be as much on me as it is the general 'weirdness' of that specific topic as well. I noticed this based on lack of feedback from them or willingness to share answers, which they are usually more than willing to do in this class."
- "The electron configuration stuff—no. When predictions were asked of them, it appeared they were successful making those predictions and I didn't really receive any questions on anything pertaining to electron configuration. More formal evidence will need to be collected the following day."

Their ability to collect evidence for student learning demonstrated not only their PCK, but also their research-minded teaching approach.

Codebook 4

Codebook 4 was used to demonstrate the motivations behind the teacher's comments. These coding frequencies are shown in Table 61 below.

Table 61. Post-Observation Survey Coding Frequencies for Observation 2 – CB4

Code	**Abbreviation**	**Frequency of Responses (*N* = 9)**	**Percentage of Total Responses (%)**
Student-focused	S-f	4	44.4
Teaching-focused	T-f	5	55.6

Taylor did not include any learning-focused motivations, but instead focused their responses on their own teaching (55.6%) and student learning (44.4%) that took place during the observed lesson.

Summary of Observation 2

Taylor taught their second progress observation over electron configuration and the quantum atomic model. The main themes for Observation 2 were:

- Taylor stated gaining teaching confidence due to increased content knowledge (KoSc) from the CHEM 770 course. They stated their ability to make different connections to the content, which they demonstrated during the observation itself. Their increased KoSc led to improved pedagogical skill and KoT. This combination of knowledge bases indicated improved PCK quality due to MS program courses.
- Although the pre-observation survey noted that the lesson contained "a bit more direct instruction than [they] like to do," Taylor involved students through

questioning and discussion frequently throughout the lesson. For a lecture-heavy lesson, Taylor maintained a student-centered classroom.

- Taylor connected their current lesson to past lessons in the course and related chemistry concepts, which encouraged students to recall information and solidify their content understanding. Similarly, Taylor made many real-world connections. These connections related to their KoG and KoCO, which revealed improved PCK quality.
- They were able to integrate assessment into their instruction, checking for understanding throughout the lesson. Taylor again collected informal evidence for student learning and used this knowledge to evaluate any potential misconceptions that arose in class. Their assessment of student learning revealed a combination of their KoSt, KoA, and KoT, which indicated higher quality PCK.
- Through the observed lesson and its surveys, Taylor demonstrated all seven components of PCK. Instances wherein Taylor combined these knowledge bases indicated improved PCK quality.

Taylor's comments before, during, and after the lesson were primarily teaching-focused (62.5%) and student-focused (31.3%) motivations, with one statement motivated by their own learning.

Teaching Script

In Spring 2022, the Teaching Script was administered at the end of the CHEM 772: Thermodynamics course. The Teaching Script was analyzed using Codebook 2 to assess participants' PCK. Table 62 displays the codes from Codebook 2 that appeared in Taylor's Semester 1 Teaching Script.

Table 62. Teaching Script Coding Frequencies for Semester 2 – CB2

Code	**Abbreviation**	**Frequency of Responses (N = 31)**	**Percentage of Total Responses (%)**
Knowledge of science	KoSc	7	22.6
Knowledge of goals	KoG	5	16.1
Knowledge of students	KoSt	7	22.6
Knowledge of curriculum organization	KoCO	3	9.7
Knowledge of teaching	KoT	6	19.4
Knowledge of assessment	KoA	1	3.2
Knowledge of resources	KoR	2	6.4

KoSc

The first component of PCK represented in the Teaching Script is KoSc, which includes science content, scientific practice, the nature of science, and scientific progress.[41] The topic Taylor chose to focus on for their Teaching Script lesson was Gibbs free energy. They then explained why they found it to be most challenging to teach, including aspects of their KoSt. Italics are original to the participant's response.

- "It's easy to teach this concept in a *superficial* way where students are technically able to calculate Gibbs Free Energy but have little to no conceptual understanding to the underlying thermodynamic principles at play that lead to a positive or negative Gibbs free energy value. Instead, a surface level understanding is achieved and all they really know is something like '*negative is spontaneous and positive is nonspontaneous*'…The algebra and unit conversions involved will always add a layer of difficulty."

Taylor provided details of their prior knowledge of Gibbs free energy and related thermodynamics concepts (KoSc).

- "Change in Gibbs free energy is equal to the max amount of work that a system can perform on the surroundings while still undergoing a spontaneous change. Chemical reactions affect the entropy of the surroundings $\Delta S_{surr} = -\frac{(\Delta H_{sys})}{T}$. The change in Gibbs free energy is based on constant temperature and pressure conditions. The change in Gibbs free energy is the difference between the heat released during a process and the heat released for the same process occurring a reversible manner. If $\Delta G = 0$, the system is at equilibrium. The sign of ΔG will indicate whether a process is spontaneous or not The units for ΔH will often be in kJ/mol while the units for ΔS will be in J/mol·K. Since ΔG is represented in kJ/mol, there will need to be a necessary unit conversion made to ΔS. Whether or not a process is spontaneous is influenced by the relationships between the system's change in enthalpy, change in entropy, and the given temperature at which the process is at."

Taylor then explained what additional knowledge they possessed beyond what they would include in their instruction.

- "The relationship between ΔG and work. This could allow for some interesting explorations about the efficiencies of various energy-converting devices."

When asked what they thought were the fundamental components of concept, Taylor demonstrated their KoSc and KoCO by making choices about what to teach about Gibbs free energy in their classes. This combination of knowledge bases indicated improved PCK quality.

- "From this prior knowledge, I believe the only fundamental components of this concept that students need to know at this level are: what the sign of ΔG indicates about the spontaneity of a process; how to calculate ΔH and ΔS for a system and make the necessary unit conversion to calculate ΔG; being able to recognize when a process is likely to be enthalpy or entropy-driven."

Summary of KoSc

Through their creation of a Teaching Script, Taylor shared their KoSc through their explanations of Gibbs free energy and related topics. The main themes for KoSc were:

- Taylor demonstrated their KoSc by describing their knowledge of Gibbs free energy and other thermodynamics topic in great detail.
- Taylor was able to evaluate their chosen topic for challenges it may pose for student understanding, which combined their KoSc and KoSt and revealed improved PCK quality.

<u>KoG</u>

The next code for the Teaching Script assignment relates to KoG, which may include learning goals for scientific literacy, real-life application, and integrated understanding.[41] When discussing their topic choice, Taylor shared one of their goals for student learning.

- "I want [students] to actually have a grasp of the circumstances in which a process is largely enthalpy or entropy-driven rather than simply 'plugging and chugging' numbers into their calculator."

Taylor then reflected on the importance of introducing their concept to their students, focusing on how the topics allows for a deeper understanding of chemical processes.

- "I believe it's important for students to understand this concept because it allows them to gain an understanding of why processes occur on their own or not. In Chemistry, we obviously talk about various chemical processes a lot. Failing to understand this concept may give the impression and any and every chemical process is likely to occur under any given set of conditions simply because we are able to write out the chemical reaction."

Connecting to their KoSt, Taylor provided real-world connections of Gibbs free energy and work. This combination of knowledge bases demonstrated improved PCK quality.

- "Since Gibbs free energy is directly related to the maximum amount of work that a system can perform on the surroundings, there are seemingly endless real-world applications of this concept as it pertains to the efficiency of various processes."
- "Another real-world connection can be found within the familiar use of hand warmers and instant ice packs. In [state], most students are familiar with these

hand warmers, but not the chemical processes that drive the mechanisms for how they work. The same goes for instant ice packs. Gaining clarity on this topic can allow for these popular consumer items to be better understood."

Summary of KoG

Taylor discussed their goals for student learning related to their Teaching Script lesson. The main theme for KoG was:

- Taylor was able to create a lesson that enabled students to gain a better understanding of chemical processes and understand real-world connections to thermodynamics concepts. This demonstrated Taylor's KoG by connecting their KoSc and KoT to create meaningful learning opportunities for students. These combinations of knowledge bases revealed improvements to the quality of Taylor's PCK.

KoSt

The next code is KoSt, which may focus on different learning levels, needs, interests, prior knowledge, ability, learning difficulties, and misconceptions.[41] Taylor chose to teach their Teaching Script lesson to their Honors Chemistry course. When discussing their knowledge of their students' thinking (KoSt), Taylor mentioned two potential misconceptions.

- "Failing to convert ΔS from J/mol·K → kJ/mol·K when calculating ΔG."
- "Thinking that a decrease in entropy will always be associated with a nonspontaneous reaction."

They then discussed potential questions and reactions from students that may come up in class during their Teaching Script lesson. These questions connect to Taylor's KoSc, while focusing on students' reception of the content. This combination of knowledge bases revealed improvements to the quality of Taylor's PCK.

- "Some possible follow-up questions I would anticipate might be: What happens if $\Delta G = 0$? How is the sign of ΔG related to equilibrium and K_{eq}?"
- "Because of the stronger mathematical reasoning skills of this class, I really don't expect much pushback or delay when it comes to the quantitative stuff. However, they are still notorious for failing to consider units in their calculations so I might expect questions related to that. Once understood, I honestly would imagine a feeling of relief from many students because now we have a simple way to focus solely on the system and consider its enthalpy and entropy values. Previously, the relationships between enthalpy, entropy, and spontaneity may have felt a bit disconnected."

Summary of KoSt

Taylor discussed their KoSt in relation to their teaching of a CHEM 772 topic. The main theme for KoSt was:

- Based on their prior experiences with students, Taylor was able to demonstrate their KoSt by anticipating student misconceptions and reactions to Gibbs free energy. They combined their KoSc and KoSt, which demonstrated improvements to their PCK quality.

KoCO

The next code relates to KoCO, which may relate to state and local standards.[41] Taylor included "the closest state standard" related to Gibbs free energy, with the following caveat:

- In [state], there are no specific state standards that directly emphasize thermodynamic understanding in Chemistry."

They also included a class learning objective related to their topic, demonstrating their KoCO by the inclusion of learning targets for their course.

- "The specific learning target for the class that relates to this topic is: I can determine whether or not a reaction is spontaneous by considering the temperature, enthalpy change, and entropy change that occurs."

After establishing the relevant standards and learning objectives, Taylor discussed how Gibbs free energy ties into their existing curriculum.

- "The concept of Gibbs free energy ties in nicely with our overall coverage of spontaneity. In this unit, students learn about why certain chemical process occur under a given set of conditions while others do not. Since there is not a heavy emphasis on thermodynamics, we primarily focus on the system rather than both system and surroundings. Since Gibbs free energy alleviates the need to calculate the entropy of the surroundings, it allows for our focus to stay on the system while still being able to predict whether a chemical process is spontaneous or not."

<u>Summary of KoCO</u>

In their responses to the Teaching Script prompting questions, Taylor described their curriculum and student learning objectives. The main theme for KoCO was:

- Taylor is aware of how Gibbs free energy fits into their curriculum, including references to learning objectives and state standards.

- Taylor also demonstrated their KoSc by discussing connections between their chosen concept and other thermodynamics topics. By combining their KoCO and KoSc, Taylor displayed improvements to their PCK quality.

KoT

The next code is KoT, which involves the discussion of teaching methods and activities.[41] First, Taylor was asked to share the teaching procedures related to their chosen lesson. They listed four components in their Teaching Script lesson, including making connections to students' prior knowledge, direct instruction, and discussion. By combining their KoSt and KoT, Taylor demonstrated higher quality PCK.

- "Recalling the evidence we had previously gathered that led to the development of the idea that in order for a spontaneous process to occur, $\Delta S_{univ} > 0$."
- "Explicitly demonstrating the usefulness of Gibbs free energy by removing the need to calculate entropy change of surroundings. This would eventually result in the derivation of the Gibbs free energy equation."
- "Continuously asking a series of guiding questions and engaging in a kind of Socratic dialogue."
- "Providing multiple of examples of when a spontaneous process is driven largely by enthalpy or entropy. Doing this will allow us to establish patterns that can support more efficient predictions of the sign of ΔG."

Taylor also discussed how they would address the potential student misconceptions described in the KoSt section through direct instruction.

- "I would address this [misconception] by showing them what happens to the unit and the overall value of ΔG when they DO and DO NOT make the necessary unit conversion."
- "I would address this [misconception] by providing examples where a process does decrease in entropy but still results in an overall $-\Delta G$ value (spontaneous). This would bring the importance that change in enthalpy plays in relation to this topic and how they can only focus on one thing (enthalpy or entropy)."

Summary of KoT

In their Teaching Script assignment, Taylor described how they would carry out a lesson on Gibbs free energy. The main themes for KoT were:

- Taylor displayed intentionality behind the order of their teaching procedures by tying in students' prior knowledge (KoSt) and their own knowledge of the structure of their topic (KoSc). This combination of knowledge bases reveals improvements to their PCK quality.
- Taylor was able to describe how they would address student misconceptions, including describing the importance of understanding the topic, which ties into their KoG. This intertwining of knowledge bases demonstrates improved PCK quality.

KoA

The next code is KoA, which details teachers' knowledge of formal and informal assessments and feedback.[41] When describing their teaching procedures, Taylor discussed assessment through the use of formative check-ins.

- "Frequent formative check-ins, likely through the use of PollEverywhere.com, to ensure conceptual understanding is achieved at various stages."

Their use of guiding questions may also contribute to their KoA; however, the statement above demonstrates their intention for assessment.

KoR

The final code in Codebook 2 relates to KoR, which discusses materials and activities that teachers utilize in their classrooms.[41] Taylor showed their KoR by describing their awareness of problems and videos related to their chosen topic.

- "Choosing from numerous available problems where students calculate ΔG under a variety of extreme conditions."
- "Choosing from numerous videos available on YouTube to supplement the understand and application of Gibbs free energy."

Summary of Teaching Script Data

Taylor's development of a Teaching Script involved their chemistry content knowledge (KoSc), their perception of the importance of teaching Gibbs free energy (KoG), their knowledge about their students' thinking (KoSt), and their understanding of how the topic fits into their curriculum (KoCO). Taylor discussed their teaching procedures (KoT), including assessment methods (KoA) and resources (KoR). The main themes from Taylor's Spring 2022 Teaching Script were:

- Taylor was able to adapt their instruction of Gibbs free energy to best suit their students' learning needs using intentionally chosen teaching procedures and assessment methods, demonstrating PCK through their KoT, KoSt, and KoA.

Taylor also combined multiple knowledge bases, which revealed improvements to their PCK quality.

- Taylor detailed their KoSc by discussing Gibbs free energy and its contribution to better understanding chemical processes, which also related to the importance of the topic and their KoG. This intertwining of knowledge bases demonstrated imprpovements to the quality of their PCK.
- Taylor was able to create a lesson on Gibbs free energy that enabled students to gain a deeper understanding of the topic, demonstrating their KoG as well as their teaching philosophy.

Module Survey – Teaching Script

After completing the Teaching Script assignment, Taylor was invited to complete a survey about their experience creating a Teaching Script for their topic. The Teaching Script module survey was coded using Codebooks 1 and 4.

Codebook 1

Coding frequencies for Codebook 1 can be found in Table 63.

Table 63. Module Survey Coding Frequencies for Semester 2 Teaching Script – CB1

Code	**Abbreviation**	**Frequency of Responses (N = 16)**	**Percentage of Total Responses (%)**
Attitudes	A-c	2	12.5
Knowledge	K-p	2	12.5
	K-c	4	25

Skill	S-p	1	6.2
	S-c	1	6.2
Teaching	T	3	18.8
Modules	M	1	6.2
Reflection	R	2	12.5

Attitudes (A-c)

In terms of current attitudes, Taylor described increased teaching confidence due to improvements to their chemistry content knowledge in the CHEM 772 course. By combining their KoT and KoSc, Taylor demonstrated improvements to the quality of their PCK.

- Increased content knowledge "has led to an increase in confidence in teaching this concept to a class of students."

When asked about their confidence level on a scale of 1 to 6 for teaching their concept, Taylor responded with a score of 5.

Knowledge (K-p and K-c)

Prior to taking the CHEM 772 course, Taylor described weaknesses in their content understanding of Gibbs free energy.

- "For this specific concept, it was a bit challenging for me [to create a Teaching Script] because I didn't really have a firm understanding of it prior to taking [CHEM 772]."

However, the CHEM 772 course filled gaps in their knowledge related to Gibbs free energy, which allowed them to create a Teaching Script and increase their KoSc, which indicated improvements to their PCK.

- "This course has certainly helped fill most of the gaps in my own understanding and that made the [Teaching Script] much easier to produce."
- "The content within this course helped fill some of the mental gaps present in my own mind about this concept. I never truly knew what exactly Gibbs free energy was. Most importantly, this course has helped me recognize the conditions in which a reaction is largely controlled by enthalpy or entropy."

In order for Taylor to gain more teaching confidence, they discussed needing further improvements to their content knowledge of CHEM 772 topics. This indicated that Taylor needs to further develop their KoSc in order to enhance their PCK related to thermodynamics topics.

- "Though it may not be specific to this particular lesson, I don't feel like I have a firm grasp of the relationship between Gibbs free energy and work. Gaining a better understanding of this might allow me to reference more applications during class to help make real-world connections for students."

The process of creating a Teaching Script helped Taylor reflect on and evaluate their own understanding of Gibbs free energy.

- "Scripting out what I plan to say, and potential student responses allow for me to have a better overall idea of whether I actually understand the thing I'm talking about."

Summary of Knowledge (K-p and K-c)

In their responses to the Teaching Script module survey, Taylor described their prior and current levels of knowledge. The main themes for this code were:

- The CHEM 772 course filled gaps in Taylor's content knowledge related to Gibbs free energy, which allowed them to teach this topic more effectively. This combination of their KoT and KoSc indicated improvements to their PCK quality. They also discussed how further improvements to their content understanding would positively impact their teaching of thermodynamics topics.
- The Teaching Script module allowed Taylor to evaluate their level of content knowledge related to Gibbs free energy and describe how they could further improve their KoSc and, therefore, PCK in the future.

Skill (S-p and S-c)

Taylor described their pedagogical skill related to teaching Gibbs free energy prior to taking the CHEM 772 course.

- "Though I had taught Gibbs free energy in the past…I didn't really have the ability to unpack its usefulness in any meaningful way."

After completing the Teaching Script assignment, Taylor was able to describe improvements to their pedagogical skill in terms of anticipating student misconceptions. This improvement to their KoT and KoSt indicated improved PCK quality.

- "Scripting out what I plan to say, and potential student responses allow for me to have a better overall idea of…my own awareness of whether I'm able to anticipate potential misconceptions that could arise from students throughout the lesson."

Teaching (T)

Taylor shared their KoT, KoG, and teaching philosophy by describing the conditions that need to be met for effective teaching of Gibbs free energy. This intertwining of knowledge bases revealed improved PCK quality.

- "Not really [feeling comfortable teaching this concept without preparing beforehand] isn't necessarily due to my own content knowledge but rather the realization that unpacking Gibbs free energy in this approach requires structure to be in place to avoid cognitive overload for students. With the derivation of Gibbs free energy equation, calculations made, and opportunities to apply the concept, there is simply too much to not have a considerable structure in place for students."

They then mentioned their desire to utilize simulations in their teaching to aid student learning of Gibbs free energy changes. This expressed their desire to improve their KoR as a component of their PCK.

- "Additionally, I wish I knew of a practical simulation, like the one from our Practice homework, where students could drag a bar to manipulate the temperature and observe how free energy changes under a variety of conditions for a reaction."

Taylor described their past instruction, reflecting on the impact their lack of content understanding had on their students' learning. This demonstrated their KoSt as a component of their PCK and indicated that improvements to their KoSc would improve the quality of their PCK.

- "Since I lacked this understanding in the past, I feel like this caused some of my students to make improper associations such as an increase in entropy of a system will always result in a reaction being spontaneous."

Summary of Teaching (T)

Through the Teaching Script, Taylor reflected on their past teaching as well as ideas related to future teaching of Gibbs free energy. The main themes for this code were:

- Taylor demonstrated their KoG and KoT by describing a structured teaching approach that would better support student learning. This combination of knowledge bases indicated improved PCK quality.
- Taylor also discussed their desire to utilize new resources (KoR) in their instruction of Gibbs free energy to further support student learning. These statements reveal Taylor's focus on a student-centered teaching approach and the potential for improved PCK.
- Taylor described the connection between their content understanding (KoSc), teaching effectiveness (KoT), and student learning (KoSt) by sharing misconceptions that occurred in the past due to Taylor's lack of KoSc. By gaining KoSc through the CHEM 772 course, Taylor improved their teaching effectiveness, which has implications for improved student learning. By combining their KoSc, KoT, and KoSt, they demonstrated improvements to their PCK quality through the CHEM 772 course.

Modules (M)

Taylor discussed the value of the Teaching Script module with the following statement:

- "I think the value in this module really comes from the fact that you must sit down and 'play out' what you anticipate taking place when teaching the topic."

The Teaching Script allowed participants to reflect on their instruction and anticipate student reactions to the content. Therefore, Taylor further developed their KoSt in combination with their KoSc, which indicated improved PCK quality.

Reflection (R)

Taylor reflected on their teaching process by discussing a lack of preparation in their past instruction of Gibbs free energy.

- "Though I had taught Gibbs free energy in the past, it always just felt like it sort of came out of nowhere."

They also reflected on the Teaching Script providing intentionality for a typical teaching preparation process.

- "As teachers, we [sit down and 'play out' what you anticipate taking place when teaching the topic] all the time to a certain degree, but it's rarely so intentional."

Codebook 4

Codebook 4 was used to identify the source of motivation that fueled Taylor's comments. Coding frequencies can be found in Table 64.

Table 64. Module Survey Coding Frequencies for Semester 2 Teaching Script – CB4

Code	**Abbreviation**	**Frequency of Responses (*N* = 12)**	**Percentage of Total Responses (%)**
Learning-focused	L-f	5	41.7
Student-focused	S-f	3	25
Teaching-focused	T-f	4	33.3

Taylor's comments from the module survey were primarily learning-focused (41.7%), but also included teaching-focused (33.3%) and learning-focused (25%) motivations. An example of each coded statement is given below.

- "This course has certainly helped fill most of the gaps in my own understanding and that made the script much easier to produce." (L-f)
- "I think the value in this module really comes from the fact that you must sit down and 'play out' what you anticipate taking place when teaching the topic." (T-f)
- "Since I lacked this understanding in the past, I feel like this caused some of my students to make improper associations such as an increase in entropy of a system will always result in a reaction being spontaneous." (S-f)

Summary of Module Survey – Teaching Script

The Teaching Script module survey allowed Taylor to reflect on their experience creating a Teaching Script and their learning and teaching of a CHEM 772 topic. Taylor's module survey responses related mostly to their learning but were also motivated by their teaching and their students' learning. The main themes were:

- The CHEM 772 course provided Taylor with increased content knowledge (KoSc) by filling gaps in their understanding of thermodynamics concepts, which led to increased teaching confidence. Improvements to their KoSc in combination with their KoT indicated improved PCK quality.
- The Teaching Script assignment allowed Taylor to anticipate student misconceptions (KoSt) and evaluate their own level of knowledge and pedagogical skill associated with the topic (KoSc and KoT). Therefore, the module supported improved PCK quality.
- Taylor's plans for their Teaching Script supported improved student learning, which highlighted Taylor's focus on student-centered instruction (KoG). This combination of their KoG, KoT, and KoSt revealed improved PCK quality.

End-of-Semester Survey

At the end of the Spring 2022 semester, I sent out an email invitation to participants of CHEM 772 and CHEM 778 to complete a survey about their experiences in core MS program courses and the MS program overall during the given semester. Taylor's responses to this survey were coded with Codebooks 1, 3, and 4.

Codebook 1

Coding frequencies for Codebook 1 can be found in Table 65.

Table 65. End-of-Semester Survey Coding Frequencies for Semester 2 – CB1

Code	**Abbreviation**	**Frequency of Responses (*N* = 22)**	**Percentage of Total Responses (%)**
Attitudes	A-c	2	9.1
Knowledge	K-p	2	9.1
	K-c	4	18.2
Skill	S-c	1	4.5
Feedback	F	8	36.4
Interaction	I	3	13.6
Reflection	R	2	9.1

Attitudes (A-c)

In terms of attitudes, Taylor discussed improvements in their teaching confidence, particularly related to their ability to implement new ideas gained from MS program courses into their teaching. Improvements to their KoT and KoR led to improved PCK.

- "Aspects that demanded a good amount of intellectual effort to be put forth (exams, research paper, projects) were meaningful to me because I felt a stronger sense of confidence in my ability to teach/implement ideas learned."
- "I feel a lot more confident in my ability to integrate such shifts in the near future as well as create more meaningful conversations with my colleagues regarding changes to our pedagogy."

Knowledge (K-p and K-c)

When reflecting on their chemistry content knowledge, Taylor shared changes in their KoSc resulting from their participation in the CHEM 772 course. They described insufficiencies in their knowledge of thermodynamics that were corrected and improved upon by CHEM 772. Taylor stated that the Spring 2022 MS program courses “improved [their] overall depth of content knowledge.” By improving their KoSc, Taylor demonstrated improved PCK.

- “772 gave me an increased depth of content knowledge that I had previously been insufficient with. I will be able to take ideas I learned about from this class and either expand or finally include in my chemistry curriculum.”
- “My knowledge of and appreciation for thermodynamics has increased tremendously. Given that it was very little to begin with, I had significant room for growth, and I felt like I made a lot of progress with that.”

Taylor also described pedagogical knowledge gains. By improving their KoT and KoR, Taylor demonstrated improved PCK.

- “Through various discussion forums and projects, I've gained insight into a wide variety of resources, ideas, and perspectives shared by other teachers.”

Skill (S-c)

In terms of pedagogical skill, Taylor discussed gaining new teaching skills that they could bring into their instruction and share with colleagues. By gaining KoT, Taylor revealed improved PCK.

- “I've also improved my ability to articulate certain pedagogical shifts in a way that makes it easier to implement and share with colleagues.”

Feedback (F)

Taylor shared eight comments coded as feedback. These statements were further analyzed using Codebook 3, which will be shared in the section below.

Interaction (I)

Taylor discussed the value of interacting with other teachers in the MS program, including gaining new perspectives and resources, and feeling connected to other program participants. The MS program supported professional development and positive PCK changes through interactions with other MS program participants.

- "Aspects of the courses this semester that placed an emphasis on interaction with other teachers helped open me up to different perspectives and I felt a stronger sense of connectivity."
- "Through various discussion forums and projects, I've gained insight into a wide variety of resources, ideas, and perspectives shared by other teachers."

Taylor also described meaningful interactions they had with instructors for the MS program. Similarly, interactions with MS program instructors supported professional and PCK development.

- "777 – the ability to meet and discuss 1-on-1 with the professor helps a great deal with thinking through ideas.

Reflection (R)

When discussing the benefit of the CHEM 778 course, Taylor reflected on the course's impact on their teaching. They reflected on how the course equipped them with the skills and knowledge necessary to teach how they "should" be teaching. They also gained “a much deeper appreciation” for involving creativity in science education. By improving their KoT, Taylor improved their overall PCK.

- “778 helped provide the necessary structure I need to be able to make the next jump in my ability to teach science in more effective and inclusive ways. I think what it did most for me was articulate many of the feelings I already had about how I SHOULD be teaching but may not have always known how to go about doing it. Also, the things I learned regarding creativity opened up an entirely new perspective on this topic that has given me a much deeper appreciation for its importance within education.”

In terms of improving their pedagogical skill, Taylor reflected on their potential improvement due to the CHEM 778 course.

- “I definitely feel like my potential for improving my pedagogical skillset has improved. I say ‘potential’ because it's so hard to just start implementing some of these pedagogical shifts immediately.”

Codebook 3

Taylor shared eight comments coded as “Feedback.” These statements were further analyzed using Codebook 3. These coding frequencies are shown in Table 66 below.

Table 66. End-of-Semester Survey Coding Frequencies for Semester 2 – CB3

Code	**Abbreviation**	**Frequency of Responses (*N* = 8)**	**Percentage of Total Responses (%)**
Assignment Feedback	AF	1	12.5
Course Feedback	CF	2	25
Program Feedback	PF	2	25
Course Delivery Feedback	CDF	2	25
Logistical Feedback	LF	1	12.5

<u>Assignment Feedback</u>

Taylor shared that the least meaningful aspect of the CHEM 778 course was the weekly e-journals.

- "I wouldn't really classify any aspects of the program courses as 'not meaningful.' Even the things that I would expect most people to label as 'not meaningful,' like discussion boards, typically had a way of generating meaning. It just may not have been as influential on me as other aspects. If I were to pick anything, it would likely be the weekly e-journals. So much reflection had already gone into the original week's discussion board that I felt like the weekly e-journal was slightly redundant. It did force me to organize and clarify ideas in a way that I may not have otherwise, but I didn't ever really feel like I was in a noticeably better place of understanding or awareness after doing a weekly e-journal."

Course Feedback

Taylor appreciated the CHEM 777 course, which helped them “chunk up” the action research component of the MS program.

- “777 - Having the structure in place that essentially chunks up the very large aspect of the research paper is incredibly useful.”

They also found CHEM 777 to have the highest value for money due to its role in helping MS program participants prepare their action research projects.

- “I ranked 777 as the highest simply because I felt that the initial structure it provides for the preparation of a much larger project is absolutely valuable. Without it, the research paper itself would feel far too overwhelming. I ranked the others just slightly lower than 777 but that's just because I didn't perceive those classes to play as much of an instrumental role in contributing to a much larger-scale end goal.”

Program Feedback

Taylor stated that nothing in the MS program failed to meet their expectations.

- “I can't really think of anything that I would identify as not meeting any of my expectations. Is there room for improvement? Sure. But nothing that I felt was completely not meeting expectations.”

Taylor also stated that the flexibility of MS program instructors exceeded their expectations.

- “The degree of flexibility professors have shown [has exceeded their expectations]. This includes things like scheduling, availability, willingness to communicate, and due dates.”

Course Delivery Feedback

In terms of course delivery, Taylor suggested having lecture videos for the CHEM 772 course.

- "As an online class, it would have been nice to have accessible lecture videos in CHEM 772. I felt like a lot of it was learning from the book and outside reading. If I were to take this class in person, I would attend lectures. Likewise, I'd like to be able to view lectures from my professor since they can often fill in those subtle gaps in my own understanding that the book may not adequately do."

Similarly, they hoped to have access to video teaching observations for the CHEM 778 course.

- "For pedagogical classes, like CHEM 778, it would be nice to have access to video observations of skilled teachers implementing certain practices and techniques we learn about in class. This isn't always easy to do but if possible, it could really add value."

Logistical Feedback

Taylor appreciated the use of the online program in CHEM 772 due to its immediate feedback.

- "Additionally, the use of the OWL (Cengage) online program in CHEM 772 for Practices, Quizzes, and Exams was incredibly useful due to its ability to provide clear feedback and provide clear, precise questions."

Codebook 4

Codebook 4 was used to analyze Taylor's motivations for statements made in the end-of-semester survey. Coding frequencies can be found in Table 67.

Table 67. End-of-Semester Survey Coding Frequencies for Semester 2 – CB4

Code	**Abbreviation**	**Frequency of Responses (N = 14)**	**Percentage of Total Responses (%)**
Learning-focused	L-f	7	50
Teaching-focused	T-f	7	50

Taylor did not include any comments motivated by potential impacts on their students' learning; however, all of Taylor's comments were split evenly between learning-focused and teaching-focused motivations. An example of each coded statement is given below.

- "My knowledge of and appreciation for thermodynamics has increased tremendously." (L-f)
- CHEM 778 "helped provide the necessary structure I need to be able to make the next jump in my ability to teach science in more effective and inclusive ways." (T-f)

Summary of End-of-Semester Survey

The end-of-semester survey gave Taylor the opportunity to reflect on their participation in MS program courses and give feedback on their experience. Half of Taylor's responses related to their own learning outcomes, while the other half were motivated by impacts on their teaching. The main themes for the Spring 2022 semester were:

- Participating in MS program courses provided Taylor with improved content knowledge, pedagogical skill, and confidence in their teaching ability. They described their ability to apply strengthened content knowledge (KoSc) to their instruction (KoT), which indicated improved PCK quality.
- Interacting with other MS program participants was valuable by creating a “stronger sense of community” among teachers and allowing for the exchange of different “resources, ideas, and perspectives.” Teachers were able to support each other’s professional and PCK development.
- The CHEM 778 course equipped them with the knowledge and skills to improve their teaching. The end-of-semester survey allowed Taylor to reflect on their current teaching practices and think about what they would change in the future. CHEM 778 allowed for improved KoT, which improved Taylor’s PCK.
- Taylor appreciated the flexibility of MS program instructors and discussed the value of the CHEM 777 course in terms of preparing their action research project. They appreciated the use of an online program in CHEM 772 that provided immediate feedback and “clear, precise questions.” They suggested that the weekly e-journals in CHEM 778 did not provide additional value on top of the discussion forums. Taylor shared feedback on CHEM 772 and CHEM 778, stating their desire to have access to video lectures and teaching observations for these courses.

Summary of Semester 2

During Semester 2, Taylor participated in the first check-in interview, the CoRe and its module survey, the CHEM 778 midway course reflection, their second progress observation and its surveys, the Teaching Script and its module survey, and the end-of-semester survey. The main themes for their second semester in the MS program were:

- Gaining chemistry content knowledge in the MS program courses led to increased teaching confidence and improved teaching effectiveness. By combining and improving their KoSc and KoT, Taylor demonstrated improved PCK quality. Taylor applied new and refreshed content knowledge to their teaching, demonstrating the direct impact of the MS program on a participant's professional development. This knowledge improvement also has implications for improved student knowledge.
- Gaining pedagogical knowledge and skill through CHEM 778 directly impacted their teaching, as Taylor had actively made changes to their instruction as a result of this course. This improvement to their KoT demonstrates improved PCK.
- Taylor's development of an action research project allowed them to reflect on how they collect data in their own classroom to improve their teaching.
- Through interactions with the MS program courses and other MS program participants, Taylor was able to develop KoSc, KoT, KoCO, KoG, and KoR, indicating improved PCK. Taylor's combinations of these knowledge bases indicate improved PCK quality. Interactions between MS program participants support professional and PCK development.
- Taylor demonstrated their KoSt and KoA – along with other knowledge bases – through their teaching observation, which further supports the existence of all PCK bases.

- Taylor's CoRe and Teaching Script demonstrated their ability to create an effective lesson plan for thermodynamics concepts, which increased their teaching confidence and effectiveness. This improvement to their KoT demonstrates improved PCK.
- Taylor discussed their contentment with choosing the MS program at SDSU while describing their need to find better balance between graduate school, teaching, family, and coaching responsibilities.
- Taylor again demonstrated their focus on a student-centered teaching approach through their CoRe and Teaching Script lessons and their teaching observation.

Summer 1

During the first summer session, Taylor took part in a course that involved coming to the SDSU campus for a two-week session. This course, CHEM 776, focused on the development of laboratory activities in conjunction with a laboratory research experience with SDSU research faculty and graduate students. Other courses were also available to the MS participants related to waste disposal, green chemistry, and chemical demonstrations; however, Taylor did not take part in these courses. All MS program courses extended past the on-campus segment, but the majority of data collection focused on the on-campus experience. Table 68 discusses the methods used during the summer session.

Table 68. Summer Data Collection Methods

Term	Data Collection Methods	ID Codes
Summer Sessions	**Before campus:**	
	Check-in Interview 3	I
	ASCI (pre)	ASCI
	Summer Journal #1	SJ
	On campus:	
	Summer Journal #2	SJ
	After campus:	
	Summer Journal #3	SJ
	ASCI (post)	ASCI
	Post-campus summer survey	PCSS
	End-of-summer survey	EOS

Check-in Interview 3

At the start of the summer session, I interviewed Taylor via Zoom to learn more about their experience in the MS program during Semester 2 and their goals for their first summer on campus. The third check-in interview was coded using Codebooks 1, 3, and 4.

Codebook 1

Codebook 1 coding frequencies are shown in Table 69.

Table 69. Check-in Interview 3 Coding Frequencies – CB1

Code	**Abbreviation**	**Frequency of Responses (N = 48)**	**Percentage of Total Responses (%)**
Attitudes	A-c	7	14.6
Knowledge	K-p	1	2.1
	K-c	3	6.3
Skill	S-p	1	2.1
	S-c	2	4.2
Goals	G	5	10.4
Experience	E	3	6.3
Background	B	6	12.5
Modules	M	1	2.1
Feedback	F	8	16.7
Interaction	I	3	6.3
Reflection	R	8	16.7

Attitudes (A-c)

Taylor described feeling increased confidence in their chemistry content knowledge (KoSc) after participating in the MS program courses, particularly CHEM 772 and CHEM 770. These courses supported improvements to Taylor's KoSc and, thus, PCK.

- “I generally felt by the time I was done with thermo I felt I had again very similar to atomic theory, I felt so much more confident and so much more whole in my ability to understand those things like entropy and enthalpy.”

Taylor enjoyed their experience in the CHEM 778 course as well.

- “I really enjoyed the [CHEM 778] class and the various routes that we got to explore.”

When reflecting on Semester 2, Taylor stated that they had a positive experience.

- “It was overall a really good experience. It was a different experience than in the fall, but it was a it was a very good experience.”

They also stated that they” don't have any pressing concerns” about the MS program at this point in time. The interview then transitioned to discussing their expectations for the summer session. They shared their attitudes toward coming to the SDSU campus.

- “I'm feeling good about coming to campus. I'm fortunate that I've been there before so I’m less worried about like the logistics of it because I've been there before. I didn't physically stay on campus, but I'm not worried about getting all hashed out.”

When thinking about the summer campus experience, they shared excitement toward participating in chemistry laboratory research.

- “I am excited genuinely to get back into a research state of mind that I genuinely haven't been part of since my undergrad. To do things where we're actually doing chemistry and doing some serious research, I’m excited to actively take part in that…Just to have a more updated fresh sense of how research is done in general nowadays is something that I'm really excited to participate in and reflect on.”

Summary of Attitudes (A-c)

When discussing their attitudes toward their experience in the MS program during Semester 2 and their first summer session, Taylor shared the following themes:

- Participating in the MS program courses improved Taylor's confidence in their chemistry content knowledge (KoSc) and pedagogical knowledge (KoT), which indicated improvements to their PCK.
- Taylor shared positive attitudes toward their experience in the MS program during Semester 2.
- Taylor was excited to come to the SDSU campus and participate in chemistry laboratory research.

Knowledge (K-p and K-c)

Taylor discussed how the three chemistry content courses they had taken through the MS program so far had improved their chemistry content knowledge (KoSc). The MS program courses enabled Taylor to enhance their KoSc, which improved their overall PCK.

- "Thermo [CHEM 772] definitely opened up my mind to a lot more content and that, to be honest, just really helps. It kind of goes back to a lot of what I said about 770 with atomic theory and 771 maybe with intermolecular forces and bonding…I have these gaps in understanding, especially with thermo. I was probably the weakest in terms of all my content understanding in thermo."

Taylor then described how gaining chemistry content knowledge in these courses allowed them to become a more effective chemistry teacher. By combining their KoSc and KoT, Taylor highlighted improvements to the quality of their PCK.

- “It's definitely helped me fill those gaps in my own content knowledge which that is one of the primary reasons I took the class…And [gaining content knowledge] in atomic theory, intermolecular forces, thermodynamics and stuff like that is something that without question has helped [become a more effective teacher]…I would say the largest thing that has directly impacted me so far in terms of working toward my goals is filling those gaps in understanding and knowledge in general that are specific to my content area.”

Taylor also discussed learning more about creativity in the CHEM 778 course.

- “Having a better sense of understanding about creativity from a cognitive point of view and kind of diving into the thick of it was something that was broadening my understanding.”

Summary of Knowledge (K-p and K-c)

Taylor described the content and pedagogical knowledge they gained through the MS program courses. The main themes for knowledge were:

- Participating in the MS program content courses allowed Taylor to fill gaps in their content understanding, which then allowed them to teach these concepts more effectively. Taylor demonstrated the improved quality of their PCK by combining their KoSc and KoT.
- Taylor gained a better understanding of creativity through the CHEM 778 course.

Skill (S-p and S-c)

In terms of their pedagogical skill, Taylor discussed how improvements to their knowledge of thermodynamics topics improved their ability to explain these topics to their students. They also described gaining teaching confidence (A-c) after participating in the CHEM 772 course. Again, Taylor combined their KoSc and KoT, demonstrating improvements to their PCK quality.

- “But we also have a thermo unit and I just thought there's always so many times where I was like, ‘when we're calculating Gibb’s free energy here's how we do it,’ and ‘what is Gibbs?’ ‘okay, well why don't we just save that for another day.’ Or I'd give a very surface level explanation of it, and so I generally felt by the time I was done with thermo [CHEM 772] I felt – very similar to atomic theory [CHEM 770] – so much more confident and so much more whole in my ability to…find out ways of how to integrate it into my classroom at this specific level so that felt really good.”

Goals (G)

Taylor described their goal to strengthen their expertise in chemistry through gaining knowledge and skills in MS program content courses. The connection they made between gaining content knowledge and improving their teaching ability demonstrates PCK.

- “I still have other content classes that I'm going to take with biochem and organic [CHEM 775] and I think that's going to be incredibly helpful. I would really like to hone my skills in my content understanding, so that I'm not just a teacher who happens to teach chemistry, but I am a I don't want to call it chemistry expert, but I am much more knowledgeable of chemistry. And therefore, in increasing my content knowledge, I can teach it better.”

Taylor stated goals related to the challenge of experiencing professional growth while balancing their other responsibilities in life.

- "I'm also trying to grow as an educator and as a person who likes learning. To know that I'm working toward something that has been challenging at various times is nice and to have overcome those things while still teaching and while still maintaining family and [coaching] and all those things is something that I've looked forward to do."

Taylor shared their excitement for being able to conduct chemistry research in an SDSU research lab, an experience that they hoped to bring back to their students. This connects their KoSc and KoT, which demonstrates potential improvements to their PCK through the summer campus experience.

- "Having the opportunity to actually do chemistry, which is something I love that I don't get an opportunity to do enough of, something that's just a bit beyond my level."
- "To have the ability to reflect on [the lab experience] and share that with my students and also to be like 'look I was doing research in 2022.'"

Taylor also shared a goal for "meeting people" through the campus research experience.

<u>Summary of Goals (G)</u>

The goals Taylor mentioned in the third check-in interview related to their educational, professional, and personal goals. The main themes for goals were:

- Taylor hoped to gain content knowledge that would enable them to teach chemistry more effectively. These potential improvements to their KoSc and KoT would improve the quality of their PCK. They reiterated their desire to experience professional growth through their experience in the MS program.

- Taylor shared their desire to participate in laboratory research on the SDSU campus. They also hoped to share details of this experience with their students, which indicates potential improvements to their PCK.
- Taylor had a goal to make connections with other MS program participants while on campus.

Experience (E)

Taylor shared experiences from their second semester in the MS program. Taylor shared their experience in their first course not related to chemistry content.

- "The spring semester was noticeably different because it was my first pedagogy class that I had taken. That was chemistry teaching strategies, so it would have been CHEM 778."

They then shared additional experiences from the CHEM 778 course. They discussed their experience with the course texts: *Ambitious Science Teaching* and *Developing Creativity in the Classroom*.[72, 73] They reflected on the value of learning about and reflecting on these pedagogical concepts. By gaining KoT, Taylor further developed their PCK.

- "A lot of what we were doing [in CHEM 778] as far as reading I love love love [*repeated for emphasis*] the books that we were reading. The *Ambitious Science Teaching*, which I had coincidentally ordered for myself the year prior.[72] It was nice to save a little bit of money because I already had the book, but it was also one of those things that, as a teacher, you get this inspiration to do [something] and usually at the beginning of the summer. And then I order it and then you have that inspiration built up and then the year happens and then 'oh, I didn't get to reading every chapter than one.' It's really nice that I was kind of forced to read every chapter and reflect on every chapter and have discussions on every chapter so it's like our own little personal book club, in a way. And so that was really nice and that actually opened up my mind to a lot of different things. Especially in the realm of managing argumentation and modeling and things that I hadn't fully fleshed out internally, and with things that I was already philosophically and even practically doing in my class but didn't have all the logistics figured out. *Developing Creativity in the Classroom* was great because we just don't talk about creativity.[73] Everybody has a sense of what it is, and so in one sense it was nice to just open my mind up to what creativity is, but then it was another thing to 'okay, how do we integrate it more, how do we value it more and demonstrate evaluation in our classrooms.'"

Taylor then shared their experience in the CHEM 777: Action Research in the Secondary Classroom course. They discussed conversations that they had with their research advisor about their project and reflected on the collaboration that took place through this course.

- "The research class [CHEM 777] was necessary…I really was thankful for the conversations I could have with Instructor B about 'am I thinking about this right?' and even just going into those conversations that there wasn't a surefire answer that it was much more organic. It was much more of they and I having a dialogue about this and I always felt very seen and stuff like that in the sense of, okay, they were aware of what I was researching and why and we'd flesh out 'well I'm not sure that's a good idea' and we'd rethink things, and so it felt very collaborative in that sense, and so I appreciated that."

Summary of Experience (E)

Taylor shared experiences they had in CHEM 778 and CHEM 777 related to pedagogy and action research. The main themes for experience were:

- Taylor described their engagement with the course texts for the CHEM 778 course that allowed them to reflect on their pedagogy. This allowed them to further develop their KoT and, thus, their PCK.
- Taylor shared the value of the collaboration they had with their research advisor in CHEM 777 when forming a research plan for their action research project.

Background (B)

In the third check-in interview, Taylor reiterated details of their educational and teaching background and discussed how it relates to their awareness or understanding of content or pedagogy.

- “Here’s this [content] that I'm generally aware of just because I've been teaching for so long and I obviously have my bachelor's in chemistry.”
- “I graduated in 2012.”
- “All the things that I've done the past 10 years of teaching pedagogy has been my primary ‘well let's improve upon this let's improve that’ sort of thing and so my interest [of pedagogy] was already there.”

They also shared details of their teaching context relating to their KoCO, which indicated the presence of their PCK.

- Their state “adopted the new kind of NGSS-like standards in 2019 and then are starting to implement next year.”

Taylor repeated details of their discussion about colleagues' experiences in other master's programs. In contrast to their own experience in the MS program, Taylor shared their colleagues' perspective of completing a "diluted" master's program solely for the financial benefit.

- "I still go back to this whole conversation about getting my master's and then you talk to other science teachers who have either already gotten their master's or are in the process of getting their master's it's like almost everybody I talk to you is just in some seemingly 'BS' program, very diluted program [and states] 'I'm taking this program with the sole intent of the financial compensation that I'm receiving as a result of completing it.'"

Taylor then discussed their interest in a teacher researcher program at a local university prior to beginning their MS degree at SDSU.

- "Throughout the past several years I've looked into a teacher researcher program trying to get teachers embedded within the research that's taking place at the [local university]. But I just never have actually done it."

Summary of Background (B)

Taylor shared details of their educational and teaching background, as well as their experience looking for a professional development program. The main themes for this code were:

- Taylor discussed graduating from with their bachelor's degree ten years ago, after which they began their teaching career. Taylor shared gaining experience with chemistry content and pedagogy through their education and teaching, detailing their baseline PCK.

- Taylor reflected on their experience searching for a program that would allow them to develop professionally. They also contrasted their experience in the MS program to that of their colleagues, whose primary goal for continued education was obtaining financial compensation.

Modules (M)

Taylor described the positive impact of reflecting on their teaching practice by engaging with the module assignments. The modules enabled them to practice and reflect on their PCK.

- “I liked the CoRe and Teaching Script. It's such a widely applicable thing that you could do for anything but to do it in something that you were previously not as comfortable with doing, but now are more comfortable doing. It's that moment to flesh out some of those things like ‘I know you feel like you're more comfortable, but how comfortable really are you in that?’ And that's having to be forced to sit down and type it out and do the script and be like ‘well, what would I talk about?’ and so that was nice to do.”

Feedback (F)

Taylor shared eight comments coded as feedback. These statements were further analyzed using Codebook 3, which will be shared in the section below.

Interaction (I)

Taylor reflected on how interactions with other MS program participants and SDSU faculty impacted their perspective on pedagogy (KoT), especially through the CHEM 778 course. Interacting with other MS program participants supported Taylor’s development of PCK.

- “And to be with other students right now and people like the professors here at SDSU to have a little bit more expertise and knowledge of those things that has given me a deeper sense of awareness of ‘okay, when I do start to implement more of these argumentation tactics, here's how I might go about doing that’ and that partly came from the *Ambitious Science Teaching* book and in the various experiences that the other teachers have shared in that class.[72] It's deepened or opened up my perspective on ways to go about implementing some of the newer standards that are not as crafted well in my pedagogy yet but are becoming to be.”

When discussing their feelings about the summer campus research experience, Taylor shared positive attitudes toward meeting other teachers in the MS program in person.

- “I’m excited to meet the other people that I've gotten to know throughout the past year, so that's been nice. Seeing somebody via Zoom is one thing, but then seeing them as an actual person, it's like you have the rest of your body and stuff like that is another thing.”

Reflection (R)

Taylor reflected on the format of the MS program, particularly relating to its online presence.

- “And within the context of it being this online class, it was really nice to share a variety of different strategies and resources. It was almost nicer than being in person because certain resources that were shared could just be shared in that moment, like ‘here is this lab and here is this website,’ whereas sometimes when you're talking to people in person, they'll reference those things, and then it's dependent upon you following up later and so there was that immediacy. But at the same time, it was also more difficult because of the online environment to understand some of the nuances behind some of the things that people were saying. I always just accepted that as part of the territory that you're going to lose a sense of nuance in an online setting than you would physically being in person, so there are pros and cons to it for sure. But at no point in time did I feel like because it's not in person that I was losing some dramatic things."

They then reflected on the challenges they faced during their second semester in the MS program.

- "Overall, it was definitely my most trying semester because I had loaded myself up with more credits than I had ever taken at that point. On top of that, it was during my [coaching] season and so it was just like holy crap, so, made it through [laughs] and things went fine, and I survived."

Taylor shared their thoughts on the value of being challenged through the MS program

- "I'm not sitting up here saying this is the Harvard of programs but I'm also saying 'look, this is challenging, I have been challenged' and this is something that I said at the very beginning that I didn't want to do something that didn't challenge me, and it has challenged me and that's something that you kind of wear as like a badge of honor but at the same time, like 'okay we're going to do this, let's do this.'"

Taylor discussed their goals for the MS program by reflecting on the value of gaining PCK through their development of KoSc and KoT.

- "I always come across various research studies over the years that are like you know one of the primary factors of being an effective teacher, especially in any field but is their content knowledge, their understanding of the subject and I was like that's one thing I really want to improve on…I've only taken one pedagogy class so far, and to hone in on [pedagogy] as well has been very nice"

Taylor then reflected on the impact of the CHEM 778 course in terms of pedagogical methods, including argumentation, creativity, and modeling. Their development of KoT improved their overall PCK.

- "Had I not taken this program there's no question in my mind, I would have gone 30 years of teaching without really giving much thought to creativity, to be honest, it's not that I would have never done anything creative in my class."
- "Instructor A has been trying to help us get more of those argumentative skills and those modeling skills and how do we get students to model things and how do we get students to participate in argumentation and whatnot and those are things that I would have otherwise done much more alone or done with colleagues who don't have that much experience with."

Taylor again shared that, although this was not their primary motivation for pursuing a master's degree, they appreciate the positive financial implications.

- "I'm not going to lie, yes, I want the financial compensation" from completing the MS degree.

Finally, they discussed their desire to conduct laboratory research in order to bring an authentic, current laboratory research experience into their teaching. By participating in research at SDSU, Taylor would have a better understanding of how research is conducted in 2022.

- "I think about some of my conversations that I have had with some of my colleagues who are like 'you know if you're ever going to do research, you know you got to have a physical lab notebook and blah blah blah.' It's not that I don't believe you but you're also saying this is how research was done in 1995 and so I [will have] done research in 2022, this is how they do research in 2022. Things have undoubtedly changed with certain equipment and certain practices and mechanisms behind how they do certain things in the research lab even in a 10-year span."

<u>Summary of Reflection (R)</u>

In the third check-in interview, Taylor reflected on their experience in the MS program, including what they have gained or will gain as a result of earning this degree. The main themes for reflection were:

- The MS program's online environment had pros and cons but did not have a dramatic impact on Taylor's learning or professional development as opposed to an in-person program.
- Taylor discussed the value of being challenged through the MS program's requirements.
- Although they discussed their desire to receive financial compensation by completing the MS degree, Taylor reflected on their primary goal to improve their PCK by applying new content and pedagogical knowledge (KoSc and KoT), which would enable them to become a more effective teacher.
- Taylor reflected on the value of gaining knowledge of current research methods through their experience in the SDSU research labs that they could apply to their

teaching. This development of KoSc would positively impact Taylor's professional and PCK development.

Codebook 3

Taylor shared eight comments coded as "Feedback." These statements were further analyzed using Codebook 3. These coding frequencies are shown in Table 70 below.

Table 70. Check-in Interview 3 Coding Frequencies – CB3

Code	**Abbreviation**	**Frequency of Responses (*N* = 8)**	**Percentage of Total Responses (%)**
Course Feedback	CF	1	12.5
Program Feedback	PF	1	12.5
Course Delivery Feedback	CDF	5	62.5
Logistical Feedback	LF	1	12.5

Course Feedback

Taylor shared feedback on the CHEM 778 Zoom meetings, stating that they appreciated the focus of each meeting on one or both course texts.

- "I liked that the Zoom sessions on Tuesday nights were somewhere clearly more allocated to [*Developing Creativity in the Classroom*] and others were clearly more *Ambitious Science Teaching* that sort of thing and others were kind of a hybrid between the two."[72, 73]

Program Feedback

Taylor shared positive feedback about their interactions with their action research advisor. They valued this collaboration and stated that working through their action research project throughout the MS program made it seem less overwhelming as a requirement.

- "I talked to Instructor B about this, if you're just saying, 'hey at the end of this master's program you're going to be doing this research project' and then if you just concentrated that all into one semester it'd be too overwhelming, so to have something where it's like, 'look, we're going to work toward this. We're going to chunk this up. There are things that you need to meet along the way.' I really was thankful for the conversations I could have Instructor B about 'am I thinking about this right?' and even just going into those conversations that there wasn't a surefire answer, that it was much more organic. It was much more of them and I having a dialogue about this and I always felt very seen in the sense of 'okay, they were aware of what I was researching and why,' and we'd flesh out 'well, I'm not sure that's a good idea' and we'd rethink things. It felt very collaborative in that sense, and so I appreciated that."

Course Delivery Feedback

When asked how the Spring 2022 semester went, Taylor discussed the pros and cons of CHEM 778 being an online course. They appreciated the immediacy of sharing strategies and resources electronically but acknowledged the loss of "nuance in an online setting." They confirmed that the online environment did not dramatically impact their learning.

- "Within the context of [CHEM 778] being this online class, it was really nice to share a variety of different strategies and resources. In an online setting, in some senses it was almost nicer than being in person because certain resources that were shared could just be shared in that moment, like 'here is this lab' and 'here is this website,' whereas sometimes when you're talking to people in person, they'll reference those things, and then it's dependent upon you following up later on, and so there was that immediacy that was there to it. At the same time, it was also more difficult because of the online environment to understand some of the nuances behind some of the things that people were saying, and I always just accepted that as part of the territory that you're going to lose a sense of nuance in an online setting than you would physically being in person, so there are pros and cons to it for sure. But at no point in time did I feel like because it's not in person, that I was losing some dramatic things."

Taylor discussed the differences in course delivery between CHEM 772 and the Fall 2021 content courses, especially in terms of access to video lectures.

- "How the learning took place in [CHEM 772] was significantly different than it was with Instructor B or Instructor A. I don't want to necessarily say it was better or worse, it was just different. With Instructor A and Instructor B, I could rely upon these lectures that were recorded, whereas in [CHEM 772] it was much more self-taught, much more book driven. It's much better if you already have confidence in this particular topic and you want to go in [to the text] for some nuance, but if you're just trying to learn something from scratch, that made it a bit more difficult."

Taylor shared the value of the online homework program in the CHEM 772 course, especially due to its immediate, specific feedback.

- "I will say once I did have somewhat of a grasp of understanding, one thing that I really loved about [CHEM 772] this year, that was not present in [CHEM 771] or [CHEM 770] was the use of the OWL. It was an online site that we would use, and I really liked it because it served as great formative work to be like 'does this one have more or less entropy' and let's just say, I chose the incorrect answer. It would immediately give me feedback, not just that your answer's wrong, but also 'here's a bunch of stuff on how you know that that answer's wrong and here's the underlying concept' – it reminded me when you would provide us feedback on the tests or on the quizzes in Instructor B's class - where your feedback wouldn't be super specific to our answer, but the feedback would be the concept and then from the concept we could derive why my particular answer was wrong and what the answer would be. It was very general feedback, but it was specific enough to that concept. I really liked that because it was automated in the [CHEM 772] class on this online thing and that's something I would have loved a lot more of in my other content classes."

Taylor discussed the value of the online software, which could be used for practice problems or formal assessments. They emphasized its value in terms of receiving immediate, specific feedback.

- "I think having something like [the OWL], where it could be used for practices, quizzes, [and] tests. Clearly it served that function, and I know it clearly must cost the school money to do so, I don't know if that is available throughout, but having that immediate feedback on practicing and even the quizzes to be available and made use of in all content classes, I think was incredibly helpful because that helped my thermo understanding grow that much easier and we all know the benefits of immediate feedback so it's not just 'hey you got 10 out of 12.' It's more like you answer this question in this particular way and here is this feedback that is conceptually driven to help it. The assessment helped with the learning, whereas I think back to we would do these really intense long practices in CHEM 770. They would be graded, but it would be delayed and the feedback that you get would be there and technically it would be more specific, but there was that delay there, and so any delay that's added into feedback makes it inherently less likely to have a positive impact on my learning. It wasn't that I didn't value the feedback. It was just this inherent built-in delay, and so that is something that could be used more widely."

Taylor reiterated the value of having an online database for video lectures from MS program instructors for content courses. They emphasized the benefit of clarifying instructors' specific explanations of chemistry concepts.

- "At the same time, having some kind of internal database of online lectures [would be helpful]. If I was [sic] physically present for this grad program, I know that you would be giving these lectures, so can we have those lectures available in each of these classes online? You say 'here are the learning targets. Okay, this one's on entropy, this one's on enthalpy.' Since we all use the same book anyway, it would be nice to have a lecture series on 'here's Chapter 1. Here's Chapter 2. Here's Chapter 3.' Again, I know that takes front loading, but at the same time it's unlikely to change, year after year after year. Since it's technically the same content, and if you wanted to you could always update it, but it would just be nice from an online point of view to be like 'okay, you are my teacher, I like hearing from you, plus it's very specific to the class,' whereas in [CHEM 772] there would be times, where I would talk to other students completely outside of the class and be like 'well, when I was researching stuff on entropy I saw this and they express it in this way, but when I did it they express it in this way,' and so there was just this ambiguity. To have a sense of clarity coming from my professor, 'here's what I'm looking for on the test' [would be helpful]."

Logistical Feedback

Taylor shared that they had logistical feedback that they elaborated on in other interviews and surveys.

- "None of [their thoughts] are concerns. Any of them would just be more tips on how to improve things, but that's more like logistical things."

Codebook 4

Codebook 4 was used to demonstrate the motivations behind Taylor's comments. These coding frequencies are shown in Table 71 below.

Table 71. Check-in Interview 3 Coding Frequencies – CB4

Code	Abbreviation	Frequency of Responses ($N = 34$)	Percentage of Total Responses (%)
Learning-focused	L-f	21	61.8
Student-focused	S-f	1	2.9
Teaching-focused	T-f	12	35.3

Taylor shared statements motivated by their primarily motivated by their own learning (61.8%) and teaching (35.3%). They shared one statement focused on their students. An example of each motivation type is given below.

- The MS program "is definitely helped me fill those gaps in my own content knowledge." (L-f)
- The MS program "has deepened or opened up my perspective on ways to go about implementing some of the newer standards that are not as crafted well in my pedagogy yet." (T-f)
- "I'm excited to actively take part in [laboratory research], and then also to have the ability to reflect on that and share that with my students." (S-f)

Summary of Check-in Interview 3

Taylor reflected on their experience in the MS program during Semester 2 and shared their hopes for the summer session. Taylor primarily shared comments motivated by their own learning (61.8%), with approximately one-third of their comments relating to their teaching (35.3%). One statement was motivated by their students' learning. The main themes from Check-in Interview 3 were:

- Filling gaps in their chemistry content knowledge and pedagogical knowledge through the MS program courses gave Taylor increased confidence and improved their teaching effectiveness. They described their plans to apply knowledge from the MS program to their teaching, which demonstrated improved PCK quality through the combination of their KoSc and KoT. These comments reveal that Taylor is achieving their goals for their time in the MS program.
- Taylor shared goals for their summer campus research experience, including making connections with other MS program participants, participating in laboratory research, and bringing back skills and details of their research experience to their students.
- Taylor appreciated collaborating with their action research advisor to prepare for the research requirement of the MS program. They appreciated the ease with which resources can be shared in the online environment but acknowledged a loss of "nuance" during Zoom conversations. They appreciated the use of an online homework software in the CHEM 772 that offered specific, immediate feedback and the focus of CHEM 778 Zoom meetings on each of the course texts. They reiterated their desire to have an online database of video lectures for the MS content courses.

Summer Journals

Participants involved in the summer session were invited to complete three guided summer journals surrounding their on-campus experience at SDSU. Each of the summer journals was coded using Codebooks 1 and 3, when applicable.

Summer Journal #1

The first journal was prompted prior to Taylor's arrival on campus and focused on their goals for the experience, both as a teacher and as a scientist, and what they anticipated the experience to be like.

Codebook 1

Coding frequencies for Codebook 1 can be found in Table 72.

Table 72. Summer Journal #1 Coding Frequencies for Summer 1 – CB1

Code	**Abbreviation**	**Frequency of Responses (*N* = 11)**	**Percentage of Total Responses (%)**
Attitudes	A-p	2	18.2
Skill	S-p	2	18.2
Teaching	T	2	18.2
Goals	G	3	27.3
Reflection	R	2	18.2

<u>Attitudes (A-p)</u>

Taylor described their hopes for the summer campus experience, including their desire for active participation in the lab and gaining knowledge about action research project logistics.

- "Whatever [the research experience] is like, I just hope that I'm involved in the process and feeling like I'm actually learning to actively participate in the research process overall."
- "Given the two weeks we have here, I'm really hoping that I can walk away with a clear idea of how to execute some of the logistical aspects for my research project. This is sort of an area of concern I have for myself because I'm not really sure how to go about the permissions, who to contact at my school, data analysis, etc."

Taylor had a strong understanding of their goals for the summer research experience and expressed their hopes and concerns.

<u>Skill (S-p)</u>

Taylor discussed two skills they hoped to gain through the campus research experience, including research problem solving and experience with instrumentation. Gaining these skills would support improvements to their KoSc and, thus, their overall PCK.

- "As a scientist, I'd like to experience that genuine feeling of trying to solve an actual problem in a research area I don't have a lot of familiarity with."
- "I want to gain experience with analysis equipment that I don't normally have access to."

Teaching (T)

In terms of teaching impacts, Taylor discussed wanting to gain new perspectives and resources relating to new lab ideas that they could bring back to their classroom. By developing KoSc and KoR, Taylor could improve their PCK related to their laboratory instruction.

- “As a teacher, I'd really like to gain some new perspectives on how to think about integrating labs in my curriculum.”
- “I'd like to gather resources from other teachers here regarding potential lab ideas.”

Goals (G)

Taylor shared three goals for their summer campus experience related to chemistry laboratory research, laboratory development, and their action research project.

- “Gain insight into what it's like doing actual chem research and communicate research experience with my students/colleagues.”
- “I'd like to be able to leave here with at least a couple labs that are readily made so that I can implement this school year.”
- “I'd also like to make considerable progress on the logistics for my research paper.”

Reflection (R)

Taylor reflected on their expectations for their first summer on the SDSU campus, as well as their goals for what skills and knowledge they want to take away from the experience.

- “This being my first summer, I honestly don't really know what to expect in the lab. I sort of anticipate that I'll be shown how certain techniques are performed and then be asked to execute those techniques to achieve a desired goal.”
- “I know I'll gain knowledge on [the action research project logistics] but it's just something in the back of my mind that I need to remember to walk out of here with.”

Codebook 4

Codebook 4 then allowed me to break down Taylor’s statements by source of motivation. Each comment was assessed to determine the focus of the comment, either focused on the participant’s learning, their students’ learning, or the participant’s teaching. Coding frequencies are displayed in Table 73.

Table 73. Summer Journal #1 Coding Frequencies for Summer 1 – CB4

Code	**Abbreviation**	**Frequency of Responses (N = 10)**	**Percentage of Total Responses (%)**
Learning-focused	L-f	6	60
Student-focused	S-f	1	10
Teaching-focused	T-f	3	30

Taylor shared statements motivated by their own learning (60%) and teaching (30%), as well as their students' learning (10%). An example of each of these motivations is given below.

- "I want to gain experience with analysis equipment that I don't normally have access to." (L-f)
- "I'd like to be able to leave here with at least a couple labs that are readily made so that I can implement this school year." (T-f)
- "Communicate research experience with my students/colleagues." (S-f)

Summary of Summer Journal #1

Taylor's first journal entry focused on their goals and hopes for the two-week campus experience. Taylor's comments focused mostly on their learning (60%) but were also motivated by their teaching and their students' learning. The main themes for Summer Journal #1 were:

- Taylor's scientific goals for summer research involved participating in the research process and gaining experience with chemistry laboratory techniques.
- Taylor's teaching goals involved developing laboratory activities to bring back to their classroom, bringing research information back to their students, and gaining new perspectives on incorporating lab into their curriculum. These goals combine Taylor's KoSc and KoT, which would potentially improve the quality of their PCK.
- Taylor also shared goals related to their action research project, demonstrating their focus on making progress toward their degree requirements.

Summer Journal #2

The second summer journal was prompted after the teachers had spent one full week on campus. The journal asked Taylor to reflect on their experience in their assigned research lab, as well as the summer courses.

Codebook 1

Coding frequencies for Codebook 1 are shown in Table 74.

Table 74. Summer Journal #2 Coding Frequencies for Summer 1 – CB1

Code	**Abbreviation**	**Frequency of Responses (*N* = 13)**	**Percentage of Total Responses (%)**
Attitudes	A-c	5	38.5
Knowledge	K-p	1	7.7
	K-c	1	7.7
Interaction	I	1	7.7
Experience	E	2	15.4
Reflection	R	3	23.1

Attitudes (A-c)

Throughout the second journal entry, Taylor expressed positive attitudes toward their experience on campus.

- The summer research experience “has been so much fun.”
- “I've really enjoyed [interacting with instrumentation].”

- "I honestly have enjoyed this whole process so far."

They also shared positive attitude changes related to their attitudes toward science due to their experiences in the research lab.

- "I feel [the research experience] has reignited my passion for actually doing science and trying to figure things out."

They also shared positive attitudes toward bringing new lab ideas into their classroom. While on campus, Taylor further developed their KoSc, KoR, and KoCO, which indicated improvements to their PCK quality.

- "As a teacher, [the summer research experience] has exposed me to some new lab ideas that I'm excited to integrate into my curriculum."

<u>Knowledge (K-p and K-c)</u>

Taylor discussed their prior understanding of analytical instrumentation and discussed knowledge changes as a result of the summer research experience. This improvement to their KoSc demonstrates improved PCK.

- "I've always been weak in my understanding of analytical instruments like NMR, HPLC, and spectroscopy but now I finally get to interact with these things in ways that are directly applicable to what I'm doing."

<u>Interaction (I)</u>

In terms of interactions, Taylor discussed the value of forming connections with other teachers in the MS program, as well as SDSU staff.

- "The staff and other classmates have all been great and I've loved making new connections with others that are also passionate about the same profession."

Experience (E)

In their second journal entry, Taylor described their experiences from their first week on campus. They detailed their time in the research lab and shared their perceptions of what they gained from the experience in terms of knowledge, skills, and resources. By gaining KoSc and KoR, Taylor improved the quality of their overall PCK.

- “It's been a really cool experience has been better than what I had expected. I'm learning so many things related to techniques and ideas within the lab that I've never gotten the chance to do. Also, I've really enjoyed the freedom we've been given to explore our own ideas within the lab. At no point have I felt like time was dragging on or anything. I'm mostly staying busy doing something within the lab and when I'm not actively doing something, I'm usually in the lab office looking up something online related to whatever technique we're working on in the lab.”
- “Since I'm finally in a place that has access to so many resources (chemicals, instruments, etc.), I'm able to actually pursue answers to many of the questions I have related to what we're doing in the lab.”

Reflection (R)

Some of Taylors comments reflected on takeaways from the research experience, especially in regard to experiences and resources they could bring back to their classroom. These statements combine Taylor’s KoSc and KoR and improved the quality of their PCK.

- “Seeing how actual chemistry research is done has been a great experience that I will want to share with my students.”

- "I would say a lot of the meaning I've derived from this experience so far has come from the research experience…The resources I've gained from other teachers so far are really meaningful as well."

Taylor also reflected on the organization of the campus experience and their feelings toward the general agenda.

- "I really like that so much is compiled into two weeks because at no point have I felt bored or anything. I like having stuff to do and being passionate about those things has made time go by really quickly."

Codebook 4

Codebook 4 then allowed me to break down Taylor's statements by source of motivation. Each comment was assessed to determine the focus of the comment, either focused on the participant's learning, their students' learning, or the participant's teaching. Coding frequencies are displayed in Table 75.

Table 75. Summer Journal #2 Coding Frequencies for Summer 1 – CB4

Code	**Abbreviation**	**Frequency of Responses (N = 8)**	**Percentage of Total Responses (%)**
Learning-focused	L-f	5	62.5
Student-focused	S-f	1	12.5
Teaching-focused	T-f	2	25

Taylor primarily shared comments motivated by their own learning (62.5%), but also shared teaching-focused (25%) and student-focused (12.5%) statements. An example of each code is given below.

- "I'm learning so many things related to techniques and ideas within the lab that I've never gotten the chance to do." (L-f)
- "As a teacher, it's exposed me to some new lab ideas that I'm excited to integrate into my curriculum." (T-f)
- "Seeing how actual chemistry research is done has been a great experience that I will want to share with my students." (S-f)

Summary of Summer Journal #2

Taylor's second journal entry focused on their first week on campus and discussed their experience in the research lab and MS summer courses so far. They primarily shared comments focused on their own learning, but also shared responses motivated by their teaching and their students' learning. The main themes for Summer Journal #2 were:

- Taylor enjoyed their first week in the research lab and expressed positive attitudes toward participating in scientific research and gaining knowledge and resources to bring back to their classroom. Their development of KoSc and KoR indicated improvements to their PCK quality.
- Their experience in the research lab inspired them to bring back details for the chemistry research process to their students, demonstrating the impact of the MS program on students' awareness of scientific research.

- Making connections with other teachers in the MS program allowed Taylor to form professional connections and gain resources for use in future teaching.

Summer Journal #3

The third and final journal entry was prompted after participants had completed their two weeks on the SDSU campus. The prompting questions asked the teachers to reflect on what they have gained through their experience, such as professional development, networking opportunities, and other takeaways. Teachers were also asked to share their thoughts on the summer session, including if their expectations were met, how the on-campus experience went overall, and any other final thoughts on the two-week session.

Codebook 1

Coding frequencies from Codebook 1 are shown in Table 76.

Table 76. Summer Journal #3 Coding Frequencies for Summer 1 – CB1

Code	**Abbreviation**	**Frequency of Responses (*N* = 18)**	**Percentage of Total Responses (%)**
Attitudes	A-c	2	11.1
Knowledge	K-c	2	11.1
Skill	S-c	2	11.1
Teaching	T	1	5.6
Feedback	F	2	11.1
Interaction	I	3	16.7

Goals	G	1	5.6
Reflection	R	5	27.8

Attitudes (A-c)

Taylor described the positive impact the laboratory experience had on their research confidence.

- "The exposure to various lab techniques and instrumentation for data analysis gave me more confidence in my own abilities to pursue ideas of interest in the lab."

They also described feeling a reinvigorated excitement toward science.

- "Being able to engage in authentic laboratory research rejuvenated my own excitement for science. Having access to so many chemicals, equipment, and instrumentation gave me that 'kid in a candy store' feeling that fueled my own curiosity to explore new ideas."

Positive changes to Taylor's teaching attitudes reflected positive professional development and improvements to their PCK through improved KoSc.

Knowledge (K-c)

When discussing how they had grown professionally during their campus experience, Taylor shared how they had gained knowledge of laboratory resources and content knowledge through the CHEM 776 laboratory development course and their experience in a research lab. These improvements to their KoSc demonstrated improved PCK.

- "Increased awareness of resources. Simply put, I left with more quality lab ideas and resources compared to when I came in."

- "Content understanding. Though there wasn't an explicit area of content focus, the variety of lab ideas I was exposed to increased my overall understanding of how different chemical ideas can be applied to various lab opportunities."

Skill (S-c)

Taylor also described how their development of laboratory skills allowed them to grow professionally during their two weeks on campus. Taylor's development of KoSc allowed for their professional and PCK development.

- "Lab techniques and skills. The lab research component exposed me to new lab techniques and skills for things such as extraction, distillation, and recrystallization methods."

Taylor also described applying these new skills to their teaching by incorporating new lab techniques into their instruction. This combination of their KoSc, KoT, and KoR indicated improved PCK quality.

- "The research experience exposed me to a wealth of new lab techniques that I will be able to actually incorporate into my own labs at school."

Teaching (T)

Taylor shared one takeaway specifically related to their teaching. They described ideas for purchasing new lab equipment for their classroom as a result of their experience in an SDSU research lab. The campus experience allowed for professional development and improved KoSc and KoR, which led to improved PCK quality.

- "I left with all kinds of ideas for future lab equipment purchases (chromatography paper, plastic test tubes with caps, vials, Vernier spectrometer, etc.)."

Feedback (F)

Taylor shared two comments coded as feedback. These statements were further analyzed using Codebook 3, which will be shared in the section below.

Interaction (I)

For Taylor, making connections with other teachers in the MS program, GTAs, and their hosting research professor was a valuable aspect of the summer research experience. They described gaining knowledge and ideas through these interactions and noted that these connections will last beyond their time on campus. These interactions supported development of KoT and KoR, which demonstrated improvements to their PCK.

- "New connections made with teachers from around the country. Finally getting an opportunity to meet classmates in person helped build relationships that will last beyond SDSU program duration."
- "Connections with graduate assistants and [research professor]. I left SDSU knowing that I can easily contact [research professor] and some of their graduate assistants if I have questions in the future."
- "I built new relationships with passionate teachers who opened me up to new ideas and opportunities that will directly impact how and what I teach."

Goals (G)

When asked if they had met the goals they had for themselves for their time on campus, Taylor responded: "I would say so, yes."

Reflection (R)

Taylor reflected on what they had hoped to get out of the summer research experience, as well as what they ended up gaining. They reflected on their involvement in their assigned research lab, new perspectives they gained on the scientific process, and the value of independence and collaboration in the lab. Their development of KoSc enhanced their PCK.

- “I believe one of the biggest things I wanted to get out of the research experience was a feeling that I was actually involved in what was taking place in the lab. The degree of freedom to explore new ideas along with appropriate guidance that was given to us was an awesome experience as both a teacher and scientist. At no point did I feel like I was just mindlessly completing tasks in the lab unrelated to my own areas of curiosity.”
- “The research experience also gave me a deeper appreciation for the overall scientific process involved with the context of formal science research. This not only includes the scientific techniques and decisions made throughout but also the dependence on financial resources when it comes to research opportunities.”
- “The degree of autonomy given was incredibly useful and I always felt like I was in a welcoming culture for collaboration of ideas.”

When reflecting on their first summer on campus, Taylor “would say it went great.” They also reflected on the value of the summer experience as a component of the MS program.

- “Regardless of whether it's your first or second summer, the experience of being there brings so much value to you as a teacher that I don't think it should be underestimated or substituted for.

Summary of Reflection (R)

Taylor used the third journal entry to reflect on their two-week experience on the SDSU campus. The main themes for reflection were:

- Taylor could describe how the summer experience allowed them to meet their goals for participating in chemistry research and gaining a better understanding of laboratory techniques, thus increasing their KoSc.
- They reflected on the value of the research experience as a teacher, demonstrating the connection between their KoSc and KoT and indicating improved PCK quality.

Codebook 3

Taylor shared two comments coded as "Feedback." These statements were further analyzed using Codebook 3. These coding frequencies are shown in Table 77 below.

Table 77. Summer Journal #3 Coding Frequencies for Summer 1 – CB3

Code	**Abbreviation**	**Frequency of Responses (*N* = 2)**	**Percentage of Total Responses (%)**
Program Feedback	PF	2	100

Program Feedback

Taylor gave positive feedback regarding their experience in their assigned SDSU research lab. They appreciated the autonomy they were given in the lab to explore new ideas.

- "I believe one of the biggest things I wanted to get out of the research experience was a feeling that I was actually involved in what was taking place in the lab. The degree of freedom to explore new ideas along with appropriate guidance that was given to us was an awesome experience as both a teacher and scientist. At no point did I feel like I was just mindlessly completing tasks in the lab unrelated to my own areas of curiosity. The degree of autonomy given was incredibly useful and I always felt like I was in a welcoming culture for collaboration of ideas."

When reflecting on the summer campus experience, Taylor felt strongly that the two-weeks on campus should remain a requirement for the MS program. They emphasized the value of the summer experience as a teacher.

- "I think this whole 2-week at SDSU experience should be an absolute requirement for completion in the program. I know it's already communicated as a requirement, but there are currently ways to attend for one summer and not the other. Regardless of whether it's your first or second summer, the experience of being there brings so much value to you as a teacher that I don't think it should be underestimated or substituted for. Even though there is a lot of stuff crammed into two weeks, I really liked it. Having stuff to do kept me busy and on task. This made the time fly by quickly and brought the necessary structure I needed in a place that I was unfamiliar with."

Codebook 4

Codebook 4 then allowed me to break down Taylor's statements by source of motivation. Each comment was assessed to determine the focus of the comment, either

focused on the participant's learning, their students' learning, or the participant's teaching. Coding frequencies are displayed in Table 78.

Table 78. Summer Journal #3 Coding Frequencies for Summer 1 – CB4

Code	**Abbreviation**	**Frequency of Responses (*N* = 11)**	**Percentage of Total Responses (%)**
Learning-focused	L-f	7	63.6
Teaching-focused	T-f	4	36.4

Taylor did not include any comments motivated by potential impacts on their students' learning; however, they provided learning-focused (63.6%) and teaching-focused (36.4%) motivations related to their experience on the SDSU campus in Summer 2022. An example of each coded statement is given below.

- "The lab research component exposed me to new lab techniques and skills for things such as extraction, distillation, and recrystallization methods." (L-f)
- "The research experience exposed me to a wealth of new lab techniques that I will be able to actually incorporate into my own labs at school." (T-f)

<u>Summary of Summer Journal #3</u>

The third journal entry allowed Taylor to describe the impact of the entire two-week campus research experience, which they felt was a vital component of the MS program. They included statements motivated by impacts to their own learning (63.6%) and teaching (36.4%). The main themes for Summer Journal #3 were:

- Developing lab skills and awareness of instrumentation caused Taylor to gain confidence in their lab research skills and contributed to their desire to pursue new scientific endeavors. The summer research experience allowed them to be an active participant in chemistry research, which positively impacted their "appreciation for the overall scientific process."
- The lab experience caused Taylor to improve their KoSc, which they planned to apply to their teaching through the inclusion of new techniques and resources for their lab activities. The intertwining of Taylor's KoSc, KoT, and KoR indicated improvements to the quality of their PCK.
- Making connections with other MS program participants, GTAs, and SDSU faculty allowed Taylor to form a support network that they felt would continue to impact their teaching and learning in the future. These connections enabled Taylor to experience professional and PCK development.
- Taylor emphasized the value of the two-week campus experience as a requirement for the MS program. They also shared positive feedback on the "degree of autonomy" they were given in their assigned SDSU research lab to "explore new ideas." The summer research experience allowed for the development of PCK through improved KoSc, as well as professional development.

Post-Campus Summer Survey

After the conclusion of the two-week on-campus session, Taylor was invited to complete a survey about their time on campus. They discussed the most and least beneficial aspects of the two-week experience, how their view of the research process has or has not been impacted by their time in SDSU research labs, and if they plan to change the laboratory work they do with their students as a result of their experience in CHEM 776. They also provided feedback for the summer courses, which will be discussed below.

Codebook 1

Coding frequencies for Codebook 1 are presented in Table 79.

Table 79. Post-Campus Summer Survey Coding Frequencies for Summer 1 – CB1

Code	**Abbreviation**	**Frequency of Responses (*N* = 13)**	**Percentage of Total Responses (%)**
Attitudes	A-p	1	7.7
	A-c	2	15.4
Knowledge	K-c	1	7.7
Skill	S-c	2	15.4
Teaching	T	1	7.7
Feedback	F	4	30.8
Experience	E	1	7.7
Reflection	R	1	7.7

Attitudes (A-p and A-c)

In order to measure any attitude changes resulting from the campus research experience, Taylor was asked to describe their perception of the research process prior to and after being on the SDSU campus. They describe the primary change in their views as being their perception of the value of failure in the research process.

- A-p: “I probably would've described the research process as something that is very methodical, tedious, and fairly linear” before arriving on campus.
- A-c: “While I still think the research process has methodical and tedious aspects to it, I think that's just a natural characteristic of doing science well. I think one of the biggest shifts in my own views on research is the importance and prevalence of failure.”

Skill (S-c)

Taylor shared the laboratory techniques they learned during their time in an SDSU research lab, highlighting their development of laboratory skills. They demonstrated improvements to their PCK quality by applying their new KoSc to their teaching (KoT).

- “The research experience and overall time spent in the lab [were the most beneficial parts of the two-week experience]. Throughout my time in the lab, I learned so many new techniques and ideas that would be relevant to improving the lab experiences of my own students.”

- "The inclusion of some basic lab techniques for separation, filtration, and extraction [in the lab they developed for their classroom] was primarily due to what I learned in the research lab."

Teaching (T)

Taylor related their experience in the research lab to their teaching by discussing changes they would make to their classroom lab activities. Taylor's comments reveal enhanced PCK quality by combining their KoSc, KoG, and KoT.

- "One of the biggest potential changes I'm thinking about making involves instrumentation and data analysis. Though I know my school will never have the same access to certain instruments (NMR, HPLC, Mass Spec, etc.), my own exposure to these instruments has caused me to place a greater emphasis on the importance of giving my own students opportunities to use more practical instruments (e.g. Vernier spectrometer) that will allow for more in-depth data analysis and concept development."

Feedback (F)

Taylor shared four comments coded as feedback. These statements were further analyzed using Codebook 3, which will be shared in the section below.

Experience (E)

Through their discussion of the campus research experience, Taylor detailed their experience communicating with GTAs in the research lab about the value of failure in the research process.

- “So many of the conversations I had with graduate assistants who were doing actual research involved discussions on how many times they failed to produce something and how that informed them what not to do in the future.”

Reflection (R)

Taylor reflected on the dissonance between doing labs in a classroom versus carrying out laboratory research.

- “We're so used to doing a lab that has a defined goal and clear path for how to get there. However, the actual research process is much more messy than that and if anything meaningful is going to come from research, it's important to welcome and appreciate the failures encountered along the way.”

Codebook 3

Taylor shared four comments coded as “Feedback.” These statements were further analyzed using Codebook 3. These coding frequencies are shown in Table 80 below.

Table 80. Post-Campus Summer Survey Coding Frequencies for Summer 1 – CB3

Code	**Abbreviation**	**Frequency of Responses (N = 4)**	**Percentage of Total Responses (%)**
Assignment Feedback	AF	1	25
Course Feedback	CF	3	75

<u>Assignment Feedback</u>

When asked about the least beneficial part of the two-week experience for them as a teacher, Taylor discussed the journal article summaries for CHEM 776.

- “Though I honestly didn't feel as though nothing was ‘not beneficial,’ if I had to pick something, it would probably be the summaries we wrote on the two journal articles of our choice. I loved the exposure to the articles but would have liked to engage more with the ideas presented within the articles instead of isolating our own ideas related to the articles by writing a summary.”

<u>Course Feedback</u>

Taylor discussed more beneficial components of the CHEM 776 course involving the journal articles and suggested having more opportunities to reflect on how they could apply the articles to their own teaching. They proposed having an opportunity to create a lesson over the journal articles in addition to the summary assignments.

- “I really liked that we got to explore the theory behind some of the articles in the morning and then implement the ideas in the afternoon. However, I felt more like a student in this context. As a teacher, it would've been nice to have more opportunities to think and act upon how I might utilize what was being described in the articles in the classroom. The paper summaries provided us with a way to think about this, but it could be supplemented with us creating our own lesson that we get to test out while on campus.”

When asked what they would change about the CHEM 776 class, Taylor reiterated the value of creating a lesson based on the journal articles. They emphasized the benefit of leaving the two-week experience with something additional to bring back to their classroom. They reflected that this exercise would support improved confidence (A-c) in regard to applying research-based practices to their teaching.

- “Opportunity for individual teachers to create an actual lesson related to at least one of the journal articles that we had originally been required to write a summary for. Writing a summary of the paper was useful, but I would've liked to leave with something tangible that I can bring back to my own classroom directly related to these articles. As a teacher, I come across journal articles like these often but struggle to translate the research article into something that can be directly utilized in my classroom. Gaining this experience would give me greater confidence to translate future articles I come across on my own into something I can implement in class.”

When asked what must not be changed about the CHEM 776 class, Taylor discussed the value of the laboratory research component. They also shared knowledge they gained as a result of this experience (K-c) that they planned to apply to their laboratory teaching approach.

- “The research component. This was such a valuable experience that it should not be overlooked. I learned so much about the application of chemistry in the lab and it fueled so many new ideas and conversations about how I might take what we were doing in the lab and apply it to my own classroom lab experience.”

Codebook 4

Codebook 4 then allowed me to break down Taylor’s statements by source of motivation. Each comment was assessed to determine the focus of the comment, either

focused on the participant's learning, their students' learning, or the participant's teaching. Coding frequencies are displayed in Table 81.

Table 81. Post-Campus Summer Survey Coding Frequencies for Summer 1 – CB4

Code	**Abbreviation**	**Frequency of Responses (N = 8)**	**Percentage of Total Responses (%)**
Learning-focused	L-f	3	37.5
Student-focused	S-f	2	25
Teaching-focused	T-f	3	37.5

Taylor's responses to the post-campus summer survey were motivated by their own learning (37.5%) and teaching (37.5%), as well as their students' learning (25%). An example of each coded statement is given below.

- "Throughout my time in the lab, I learned so many new techniques and ideas." (L-f)
- The research experience "fueled so many new ideas and conversations about how I might take what we were doing in the lab and apply it to my own classroom lab experience." (T-f)
- "My own exposure to these instruments has caused me to place a greater emphasis on the importance of giving my own students opportunities to use more

practical instruments (e.g. Vernier spectrometer) that will allow for more in-depth data analysis and concept development." (S-f)

Summary of Post-Campus Summer Survey

In the post-campus summer survey, Taylor reflected on their two-week campus experience, including their participation in the CHEM 776 course and their time in an SDSU research lab. Taylor's comments were motivated by their own teaching and learning, as well as implications for their students' learning. The main themes for this survey were:

- One of Taylor's biggest takeaways from the research experience was appreciating the value of failure in the research process, something they planned to bring into their teaching of labs. This experience impacted Taylor's teaching philosophy and professional development.
- Developing new laboratory knowledge and skills allowed Taylor to improve their KoSc and apply it to their teaching, connecting to their KoG and KoT. By increasing and combining these knowledge bases, the summer research experience improved Taylor's PCK quality.
- Taylor valued the laboratory research component of the CHEM 776 course and gained knowledge and skills that they planned to apply to their laboratory teaching approach. Their development of KoSc enhanced their overall PCK. They suggested allowing for opportunities to create lessons based on educational research articles discussed in the CHEM 776 course, in addition to the journal article summary assignments.

ASCI (pre/post)

Taylor completed both the pre- and post-test of the ASCI. Pre/post data are displayed in Table 82. According to Bauer, the percentage scale indicates the level of the given category that a participant has with respect to Chemistry Laboratory Research, in our case.[64] The categories of attitudes in the inventory include emotional satisfaction, anxiety, intellectual accessibility, interest & utility, and fear.[64] Bauer indicates that a higher score or percentage indicates a higher degree of the attitude; for example, a higher score for anxiety indicates more anxiety and a higher score for emotional satisfaction indicates higher emotional satisfaction.[64]

Table 82. Narrative ASCI Pre/Post Data with Respect to Chemistry Laboratory Research

	Emotional Satisfaction (%)	Anxiety (%)	Intellectual Accessibility (%)	Interest & Utility (%)	Fear (%)
Pre	67	40	40	87	33
Post	67	33	40	93	50

Taking these clarifications into account, we would hope to see an increase in emotional satisfaction, intellectual accessibility, and interest & utility; conversely, we would hope to see a decrease in the teachers' anxiety and fear surrounding chemistry laboratory research.

For emotional satisfaction and intellectual accessibility, Taylor's score did not change after the 2-week research experience. Taylor experienced 7% less anxiety after the two-week experience. In terms of interest & utility of chemistry laboratory research, Taylor experienced a 6% shift toward higher interest and utility. The data for fear indicates that Taylor became 17% more fearful of chemistry laboratory research after the summer experience.

End-of-Summer Survey

The end-of-summer survey follows the same format as the other end-of-semester surveys and focuses on what knowledge and skills teachers gained from the summer research experience, along with feedback that participants have shared. Taylor's end-of-summer survey responses were analyzed using Codebooks 1, 3, and 4.

Codebook 1

Coding frequencies for Codebook 1 can be found in Table 83.

Table 83. End-of-Summer Survey Coding Frequencies for Summer 1 – CB1

Code	**Abbreviation**	**Frequency of Responses (N = 20)**	**Percentage of Total Responses (%)**
Skill	S-c	3	15
Teaching	T	3	15
Feedback	F	6	30
Interaction	I	3	15
Reflection	R	5	25

Skill (S-c)

Through their experience in an SDSU research lab, Taylor discussed improvements to their KoSc through their development of chemistry laboratory skills, which improved their overall PCK.

- "Most of my content knowledge that was improved this summer focused more on technique in the lab rather than actual chemistry content itself."
- "Learning about so many different laboratory techniques and instrumentation was super helpful."

They also discussed the impact of their laboratory research experience on their pedagogical skill in terms of teaching lab activities. This combination of their KoSc and KoT led to improved PCK quality.

- "I think [the campus research experience] helped me to be a bit more open to the emphasis on the exploratory phase throughout the lab process."

Teaching (T)

Taylor also shared that the most valuable aspects of the summer experience were those that could translate to their teaching. This comment indicates professional and PCK development through the summer campus experience.

- "Anything that ends up in me producing something that is essentially ready to implement in my classroom is very valuable to me."

These aspects primarily related to their own exposure to lab techniques and the role of labs in chemistry education. Improving and combining their KoSc and KoT led to improved PCK.

- "Learning about so many different laboratory techniques and instrumentation…gave me a bunch of ideas for new sensors and applications I could use in my own classroom."
- They became a more effective teacher this summer "by gaining a greater understanding of the important role the lab can play in my students' learning of chemistry."

<u>Feedback (F)</u>

Taylor shared six comments coded as feedback. These statements were further analyzed using Codebook 3, which will be shared in the section below.

<u>Interaction (I)</u>

Taylor discussed the value of interactions that took place while they were on campus. By interacting with other teachers in the program, they were able to exchange teaching ideas and learn about others' experiences defending their action research project. These interactions supported improvements to Taylor's KoT and KoR as components of their PCK, as well as their professional development.

- "Being able to network with other teachers generated greater exposure to new ideas that can help me be a more effective teacher."
- "Being able to see how other students that had already completed their master's [action research project] went about their defense was helpful as well."

Taylor also discussed the value of interacting with an instructor for the MS program, particularly in relation to their action research project.

- "For 777, having direct access to Instructor B for guidance along the way was very helpful."

Reflection (R)

In the end-of-summer survey, Taylor reflected on how the summer research experience was meaningful for their learning and professional development. They described how their time on campus allowed for improvements to their KoSc and KoT, which positively impacted their PCK.

- The summer research experience “was very beneficial to me because of all the new ideas and techniques I was exposed to. It was great to actually participate in the science process and continuously make connections from my experiences in the lab, to those in my own classroom.”
- CHEM 776 “exposed me to several great ideas when discussing the different articles. If nothing else, it provided a nice template for how my own department could access, analyze, and interpret journal articles for potential use in our own classrooms.”

They also reflected on their expectations for the summer program. Taylor’s comments related to the value of having independence in the lab and gaining new ideas and skills. By gaining KoSc, Taylor enhanced their overall PCK.

- “The amount of freedom and autonomy we were given in the lab to explore ideas” exceeded their expectations.
- “For 776, the lab experience was completely worth it based on the ideas and techniques I learned along the way.”

Taylor also described the value of being exposed to new instrumentation in their assigned research lab. The laboratory experience improved their KoSc as a component of their PCK.

- “Access to a variety of instruments and equipment opened me up to a bunch of things I had never done in the lab before.”

Summary of Reflection (R)

The end-of-summer survey allowed Taylor to reflect on their overall experience in their assigned research lab and the summer courses. The main theme for reflection was:

- Taylor described the value of being exposed to new laboratory techniques and ideas due to their implications for improved teaching. This combines their KoSc and KoT, which evidences improved PCK quality due to the summer campus experience.

Codebook 3

Taylor shared six comments coded as “Feedback.” These statements were further analyzed using Codebook 3. These coding frequencies are shown in Table 84 below.

Table 84. End-of-Summer Survey Coding Frequencies for Summer 1 – CB3

Code	**Abbreviation**	**Frequency of Responses (*N* = 6)**	**Percentage of Total Responses (%)**
Assignment Feedback	AF	2	33.3
Course Feedback	CF	2	33.3
Program Feedback	PF	2	33.3

Assignment Feedback

Taylor discussed the value of creating a laboratory-based activity that they could envision implementing in their own classroom.

- "Additionally, the laboratory-based activity was a very meaningful experience because it required me to engage with it in such a way so that I could take the time to see what this would look like in my classroom if I were to implement it."

In regard to aspects of CHEM 776 that were not as meaningful, Taylor discussed the redundancy of the summary papers.

- "The summary papers were probably less meaningful to me simply because much of what we discussed in the face-to-face meetings did a good job summarizing and critiquing each of the papers already. Though I think there is some value in sitting down and really digging into the paper on your own to generate a summary, it sort of felt a little redundant at times."

Course Feedback

Taylor discussed the meaningful aspects of the CHEM 776 course. They first reflected on the value of the class discussions on educational journal articles.

- "Both as a teacher and learner, the face-to-face discussions were really meaningful because of the variety of input shared between other teachers as well as the opportunity to actually engage with journal articles that went beyond simply reviewing them."

They emphasized the value of discussing the journal articles both in the morning and the afternoon.

- "The fact that we discussed more of the theory behind the article in the morning and then actually apply the underlying theory in the afternoon was a valuable experience."

Program Feedback

In terms of changes they would make to improve the MS program, Taylor suggested allowing for more engagement with instrumentation while on the SDSU campus.

- "If I had to suggest something, it might be more of an emphasis on utilizing some of the instrumentation that the university has access to (HPLC, NMR, Mass Spec, etc.). Having access to those devices was so cool and I would've loved to learn more about them."

Taylor emphasized the value of the summer campus experience as a requirement for the MS program.

- "The 2-week summer program was great, and I hope it continues to be a requirement for the program!"

Codebook 4

Codebook 4 then allowed me to break down Taylor's statements by source of motivation. Each comment was assessed to determine the focus of the comment, either focused on the participant's learning, their students' learning, or the participant's teaching. Coding frequencies are displayed in Table 85.

Table 85. End-of-Summer Survey Coding Frequencies for Summer 1 – CB4

Code	**Abbreviation**	**Frequency of Responses (*N* = 16)**	**Percentage of Total Responses (%)**
Learning-focused	L-f	9	56.2
Student-focused	S-f	1	6.2
Teaching-focused	T-f	6	37.5

Taylor's responses to the end-of-summer survey were primarily motivated by their own learning (56.2%), but they also included teaching-focused (37.5%) and student-focused (6.2%) motivations. An example of each motivation type is given below.

- "The lab experience was completely worth it based on the ideas and techniques I learned along the way." (L-f)
- "Anything that ends up in me producing something that is essentially ready to implement in my classroom is very valuable to me." (T-f)
- Taylor became a more effective teacher "by gaining a greater understanding of the important role the lab can play in my students' learning of chemistry." (S-f)

Summary of End-of-Summer Survey

Taylor discussed their overall experience in the MS program during the Summer 2022 term and revealed the value of the summer campus component of the MS program. Their responses were primarily motivated by their own learning and teaching, but also included implications for student learning. The main themes from their responses to the end-of-summer survey were:

- Taylor's experience in an SDSU research lab exposed them to new laboratory techniques and instrumentation that they planned to bring into their teaching. The connections they made between their KoSc and KoT demonstrated improvements to their PCK quality.
- The discussion of educational research related to laboratory activities also impacted their teaching (KoT) and demonstrated their KoG by discussing implications for student learning, which led to improved PCK quality.
- Interactions with other MS program participants and instructors positively impacted their teaching effectiveness and their progress toward completing the MS degree. These interactions supported positive PCK change and professional development.
- Taylor appreciated the face-to-face discussions of journal articles in CHEM 776, as well as the laboratory-based activity component of the course. Taylor felt that these discussions could adequately replace the summary paper assignments. They suggested allowing for greater access to instrumentation while on the SDSU campus and emphasized the value of the summer campus experience as a requirement for the MS program.

<u>Summary of Summer 1</u>

Taylor's responses to interviews, surveys, and journal prompts demonstrated the impact of the summer component of the MS program. The main themes for their first summer in the MS program were:

- Gaining chemistry content and pedagogical knowledge in MS program courses improved Taylor's confidence and teaching effectiveness. Taylor applied their new KoSc to their teaching (KoT), demonstrating improved PCK quality resulting from the summer campus experience.
- Prior to coming to campus, Taylor hoped to gain knowledge of the research experience that they could share with their students. They also hoped to gain new perspectives on incorporating lab activities into their curriculum. By attaining these goals, Taylor would experience professional and PCK development.
- After the two-weeks on campus, Taylor described gaining research skills and knowledge, feeling inspired to share their research experience with their students, and planning to include new techniques and resources in their teaching of lab activities, which indicated that they met their goals for the summer session. By increasing and combining their KoSc, KoT, KoCO, and KoR, Taylor enhanced their PCK quality. The discussion of chemical education research in CHEM 776 and their participation in laboratory research positively impacted their teaching.
- Taylor met their goal to make connections with other MS program participants, GTAs, and SDSU faculty while on campus, forming a supportive professional network that they felt would last past their time in the MS program. These connections allowed for Taylor's professional and PCK development.

Semester 3

During Semester 3, Taylor participated in two chemistry content courses. CHEM 774 focused on electrochemistry, kinetics, and nuclear chemistry topics. CHEM 775 focused on organic and biochemistry topics. These courses were fully online and primarily asynchronous. Optional weekly Zoom sessions were offered for each course and were the only synchronous components. The data for Semester 3 is presented chronologically. Two check-in interviews took place via Zoom at the beginning and end of Semester 3. Taylor participated in a progress teaching observation, along with pre- and post-observation surveys, near the end of the semester. The CoRe and Teaching Script assignments were both due near the end of the semester, along with module surveys. The End-of-Semester survey was sent out after the conclusion of the semester. Table 86 discusses the methods used during the Semester 3.

Table 86. Semester 3 Data Collection Methods

Term	**Data Collection Methods**	**ID Codes**
Semester 3	**CHEM 774:**	
	Teaching Script	TS
	Module Survey	MS
	CHEM 775:	
	CoRe	CoRe
	Module Survey	MS
	General:	
	Check-in Interview 4	I
	Teaching Observation	TO
	Check-in Interview 5	I
	End-of-Semester Survey	EOS

Check-in Interview 4

At the start of Semester 3, I interviewed Taylor via Zoom to learn more about their two-week summer campus experience and their goals for their third semester in the MS program. The fourth check-in interview was coded using Codebooks 1, 3 and 4.

Codebook 1

Codebook 1 coding frequencies are shown in Table 87.

Table 87. Check-in Interview 4 Coding Frequencies – CB1

Code	**Abbreviation**	**Frequency of Responses (N = 44)**	**Percentage of Total Responses (%)**
Attitudes	A-c	2	4.5
Knowledge	K-c	2	4.5
Goals	G	5	11.4
Experience	E	7	15.9
Background	B	2	4.5
Modules	M	1	2.3
Teaching	T	7	15.9
Feedback	F	5	11.4
Interaction	I	3	6.8
Reflection	R	10	22.7

Attitudes (A-c)

Taylor shared their excitement for learning more about nuclear chemistry topics in CHEM 774 this semester. They expressed interest in improving their KoSc, which would improve their overall PCK.

- "I'm really excited that I'm going to be learning more about nuclear in Instructor A's class in 774 from a content point of view."

They then shared attitude changes related to a renewed empathy for their students. Being a student in the MS program enabled them to understand their students' experiences, especially related to test anxiety.

- "It's also, I think I kind of felt this after the fall semester, but now that I have a year of it under my belt it's kind of funny how being a student again, especially in an online environment, you start to have developed more empathy for your own students on turning in things, the amount of time it takes to do said things at home, and stuff like that. And even the little subtle feelings like the stress of a test. When taking an online test, and even knowing that I have an opportunity to maybe retake it, the nerves of it. As a teacher you give your tests, and then you just go sit back down and monitor and you just don't really think about that. So ten years of doing that, you kind of lose empathy for kids that say they have test anxiety. It's like all right, whatever, just know this stuff. But I can see even though I don't have test anxiety I can see kind of where it comes from, because if I'm getting kind of nervous at the beginning of the test, and somebody else is very likely to get nervous, and they don't know the material all that well, then I can see those things coming together in a negative way. That's something I hadn't really totally thought about before. There's more empathy for the students."

Knowledge (K-c)

While on campus for the summer research experience, Taylor discussed gaining experience and knowledge of chemistry techniques. By gaining KoSc, Taylor improved their PCK.

- "I just learned a whole bunch of chemistry techniques on things that I was aware of but didn't know exactly how to do."

After their first year in the MS program, Taylor felt that they generally gained more knowledge, which allowed them to make more connections. Improving their KoSc led to improvements to their overall PCK.

- "I think I have more ideas. I know more, which sounds stupid, but I just know more stuff. You can't help but see the potential for new connections to things."

Goals

Taylor discussed goals they have for the remainder of their time in the MS program, as well as progress they have made toward their goals. They first discussed goals for preparing for the execution of their action research while balancing MS course expectations.

- "Some of my goals are I need to get the logistical stuff done. I've already got permission from the building administrator. The consent forms, the IRB stuff, my plan is to get that done all before school starts. I won't actually be implementing my research until December-ish because it's when we hit stoichiometry, so I know I have a little bit of time, but I just want to get that out of the way. So that's a big goal is to be in a position where come December, I'm not freaking out to get everything in order. I want my ducks in a row come November truthfully so that way I can just go. And while at the same time balancing the organic and the kinetics."

They also had goals for gaining more nuclear chemistry knowledge in CHEM 774 that they could implement into their spring curriculum. This would combine their KoSc and KoCO, which would improve the quality of their overall PCK.

- "But I'm more excited to get into a deep dive into the nuclear stuff, especially as it relates to energy sources and whatnot. So that's a big goal for me is to find ways to bring something to the table come next spring."

Similarly, they hoped to take away knowledge and resources from CHEM 775 to bring more organic chemistry topics into their instruction. This indicates interest in improving their KoSc and KoR, which would improve their overall PCK.

- "So I say all that to say now I'm taking organic this fall kind of in the same light as nuclear. If I were to teach organic at a high school level like we have been, I'd like to have more ways, more resources, more awareness than just going beyond nomenclature."

After sharing goals related to the MS content courses, they reiterated their overall goal for gaining content knowledge through the MS program's requirements that could be applied to their teaching. They also confirmed that the MS program is meeting their expectations for that goal. This indicates improvements to Taylor's PCK due to MS program content courses. By combining their KoSc and KoT, Taylor demonstrated improvements to their PCK quality.

- "I didn't take this program necessarily with the sole intention to become more exposed to pedagogical things as I did to really dive deeper into my own content understanding. And I feel like I'm getting that while at the same time, with that new content that I'm learning, I would also like to, you know, find ways to integrate that into my teaching. I feel like we're doing that."

They discussed their goal to execute their data collection well, regardless of the results.

- "I'm just really hoping that the research goes well, whatever that means. I just want it to be executed well, to say that I did it well, and whatever the results are, the results are."

Summary of Goals

Taylor described their goals for the MS program related to their chemistry content knowledge and action research project. The main themes for goals were:

- Taylor hoped to prepare for their action research project and execute their data collection well by the end of the Fall 2022 semester.
- They hoped to gain chemistry content knowledge and resources from the CHEM 774 and CHEM 775 courses, which they then hoped to apply to their own teaching. This goal reveals their desire to improve their PCK through the MS program and confirmed that the MS program is helping them accomplish this goal. By combining their KoSc and KoT, Taylor demonstrated improvements to their PCK quality resulting from their experience in the MS program.

Experience

Taylor discussed their experience in the CHEM 776 course, describing the morning journal article discussions that they would carry out in the lab during the afternoon session.

- "But then also professionally getting the amount of opportunities to talk about pedagogical stuff within the context of specific chemistry activities. I really, really liked [how in 776] we would basically discuss theory in the morning and then…in the afternoon be basically given the materials to actually execute it. You end up thinking [of] ways that you could potentially modify it to fit your needs. So that was really cool."

When reflecting on why they didn't take the demonstrations or waste disposal classes, they discussed their experience registering for the required summer courses.

- "I just did the thing that was classic me. Just tell me what to do to complete the program, and then I'll sign up for that. And so I signed up for the summer thing that everybody did: 777 and [776]. And then that was that, and I just didn't give much thought to anything else."

Similarly, they stated which classes they are taking in the Fall 2022 semester.

- "I'm taking all of them. So the two Content [CHEM 774 and CHEM 775] and the 788, which is just me executing my research."

When reflecting on their research, they shared their experience of making progress toward a specific research goal, then making the choice to shift to a new topic.

- "With respect to my research, I took a little bit of a non-traditional path where I had my paper written after taking [Instructor B's] 777 class. The more I thought about it after talking with all the teachers I was like, ‘I don't think I want to do this topic,’ which sucked in a way because I had committed already so much time and effort to writing my paper and researching. I would have never scrapped it had I not felt like I came up with a better idea. It was more applicable and practical, and it was interesting to me at the same time related to stoichiometry. So that's the route that I’m going now. I won't say back at the starting line, but I mean with respect to the paper, I am.”

Relating to interactions, Taylor again discussed the teacher-initiated study groups that they participated in apart from MS program requirements.

- The study groups have “also really helped because how I approach the types of questions, and how I talk about a problem that I would just because it's informal. You’re all in the same playing field because you're all students in this situation, just the level of comfort and openness of the questions that you may have are just going to be different than if you're talking to [MS program instructors]…Some people would come in with nine of the thirteen problems done already, and I remember times where I'd come in with zero of them done. And just be like, ‘okay, I'm just going to sit back and kind of listen to you guys talk about some of these.’ so that you can still learn from them and ask questions in that moment.”

Taylor stated that these study groups did not take place “last spring” of 2022 because there was only a single content course.

Summary of Experience

Taylor described experiences that occurred during their time in the MS program. They discussed the daily schedule of CHEM 776, registering for MS program courses, preparing their action research project, and participating in teacher-initiated study groups.

Background

Taylor described the institution of new state science standards that has impacted their curriculum. Apart from the MS program, this statement indicates Taylor's increased KoCO, which impacts their PCK.

- "This is the first year that [state] released new science standards. I think because of COVID they delayed the required years that they need to be implemented either to this year or next year. But anyways it's the first year where we have legit nuclear standards where we get to learn about all sorts of things with nuclear especially related to nuclear energy."

They also reflected on their involvement in study groups in college, similar to the study groups they described for the MS program, which aided their past learning of challenging topics. Taylor discussed the impact of study groups on supporting their further development of KoSc as a component of their PCK.

- The study groups "reminded me of college to be honest. Once the content started getting hard for me, I realized I needed to find a group of people that to be honest are smarter than me and help me with physical chemistry, for example, because integrating calculus with chemistry was not fun."

Modules

Taylor described the impact of the CoRe and Teaching Script modules on their approach to teaching, particularly related to their lesson or unit planning. Thus, the modules impacted Taylor's KoCO and KoT as components of their PCK and indicated improvements to the overall quality of their PCK by combining these knowledge bases.

- "I think the way I plan things is a bit more structured because I've been working on and off with a colleague the past few weeks just kind of getting the ball rolling for this school year, especially with the new standards, and it's not that I literally pull up those CoRe and Teaching Script, but those assignments have reminded me that you can actually structure either a lesson or a unit by asking a specific subset of questions. That is a template that will allow for, 'if I answer this question, then that can lead to this question,' and that just helps my brain navigate through the unit because we're really revamping a lot of stuff. I think [the MS program] helped teach me how to be more structured with my planning."

Teaching

Taylor first discussed how they planned to bring new knowledge of CHEM 774 and CHEM 775 topics into their teaching, particularly related to their past teaching of nuclear and organic chemistry. These statements combine Taylor's KoSc and KoT and demonstrate improvements to their PCK quality resulting from MS program courses.

- They're excited to "find ways to integrate [CHEM 774 content] into [their teaching] - nuclear for us will be in the spring toward the end. I've taught nuclear in Honors before, but it's always just been this quick little two-week unit, just because we had some time."

- "I'm dissatisfied with how we do organic. We say we do organic in my school, but really, it's just a two-and-a-half-week spiel on nomenclature and a couple demo reaction types where they make an ester that smells like this. I mean, we do do one where we produce the acetaminophen that sort of thing, but it's nothing crazy."

Taylor discussed their students' interest in their current teaching of organic chemistry nomenclature, demonstrating their KoSt as a component of their PCK. They then shared their desire to add more to their organic chemistry curriculum based on what they learned in CHEM 775. This combines their KoSc and KoCO, which demonstrates improved PCK quality.

- "The kids like nomenclature, but it's just because it's very algorithmic and it's fun. I'm not going to lie, it's fun. It's like a puzzle. The kids that don't traditionally do well in chemistry end up doing well with organic nomenclature because it's a language, so you just have to learn it. I'd like to just beef it up a little bit."

When discussing any changes they have made to teaching after their first year in the MS program, Taylor discussed impacts from multiple content courses and the summer research experience. They first reflected on their desire to integrate new topics and ideas from the MS content courses they have taken. This intertwining of their KoSc and KoCO demonstrate improvements to the quality of Taylor's PCK.

- "Now at the beginning it's a little hard because from a content point of view, we start off with gases, and then in nomenclature. But as we get into reactions, I start to think about some of the demos that Instructor A has done and shown us, and the ways in which we've thought about integrating those things in any of the content classes that I've taken. If we happen to be learning about that kind of content in school, then [they] find ways to integrate that."

They reiterated their mindset toward implementing new ideas and content into their curriculum because of their participation in MS courses. They also discussed a CHEM 771 demonstration that inspired them to make changes to a similar demonstration they performed in their baseline observation. This demonstrates Taylor's combination of their KoR, KoCO, and KoT gained in the MS program, which reflects improvements to their overall PCK quality.

- "Since we start with gases – when I took intermolecular forces with Instructor B last year, there was a liquid nitrogen demo for ideal versus real gases. And we're integrating that demo into our unit one, as far as when gases deviate from ideal behavior. That's kind of an example of what I'm talking about, like, 'Okay, I wasn't aware of X. But now that I am aware of X, I find a way to integrate X into my curriculum.'"

Finally, they discussed the impact of the first summer experience on their lab instruction. They hoped to bring new lab techniques and demonstrations into their teaching. This combination of their KoSc and KoT demonstrates improvements to their PCK quality due to the campus summer experience.

- "The experience this summer has also gotten me to try to be more inquisitive about finding ways to integrate more lab experiences into the classroom. Not to say that we were ever iffy on labs or it was too diluted, but from a measuring point of view finding resources to get funds for sensors and different techniques that I learned that I could bring to here, even cheap ones, and just different little demos and stuff like that."

Summary of Teaching

Taylor discussed how their participation in the MS program has impacted their teaching. The main themes for teaching were:

- Taylor hoped to bring new ideas from the Fall 2022 content courses into their teaching of nuclear and organic chemistry, which indicated enhanced PCK through improved KoSc.
- Taylor reflected on how they have integrated new content and ideas from their first year in the MS program into their teaching. They also described positive changes to their lab instruction approach due to their summer campus experience. These comments combined Taylor's KoSc, KoCO, KoT, and KoR. These teaching changes highlight improvements to the quality of Taylor's overall PCK due to MS program courses and interactions with fellow MS program participants, instructors, and GTAs.

Feedback

Taylor shared five comments coded as feedback. These statements were further analyzed using Codebook 3, which will be shared in the section below.

Interaction

Taylor discussed the value of meeting other MS program participants in person, forming both professional and personal connections. These interactions allowed for the exchange of KoR and KoT, which demonstrated the MS program's impact on its participants' PCK.

- "The synopsis of it was is that it was a really good experience, both professionally to get to know new people – we've been in study groups, and we've met via Zoom a bunch of times, but to meet them in person, and just to talk about teaching and share materials, but other times just be people and get to know them and [have] that camaraderie – that's special."

Taylor reiterated the value of the teacher-organized study groups, stating that they got to know their fellow MS program participants personally, which laid a social foundation for their time on the SDSU campus.

- "It's been great. To be honest the people who are in that study group are closer to each other than we all are to the people who aren't right? It's hard not to be social in those scenarios and just get to know each other a little bit, and just small talk even and that way it's just like, 'Oh, yeah, I know stuff about you when I meet you,' or just makes it that camaraderie."

<u>Reflection</u>

Taylor reflected on their experience in their first year of the MS program, including the two-week campus experience, and shared their thoughts on the upcoming semester. First, Taylor talked about the value of engaging with the literature and applying ideas from journal articles in CHEM 776. These discussions improved Taylor's KoT and KoR as components of their PCK.

- "But I thought that was really cool, because a lot of us have - I've had access to J. Chem Ed for years, and I'll read through articles, but oftentimes you end up, leaving it being like 'Hm! That's a cool idea.' And then it just goes out the window, or it might be something to think about later on. And maybe, maybe you end up implementing it. But this way it was cool because it was a very dedicated time to talk about basically the theory behind it, the underlying things."

They reflected that not every journal article was something they would implement in their classroom, but that interacting with the literature was a valuable experience nonetheless to gain KoT and KoR as components of their PCK.

- "Sometimes not of all of them were home runs. But that's why you do it right? It might sound like a really applicable idea theoretically."

When reflecting on the research component of the CHEM 776 course, Taylor discussed their appreciation for the opportunity to work with lab instrumentation and equipment. This experience enabled them to gain KoSc as a component of their PCK.

- "From a learning point of view, there were times where it was just like a kid in a candy store. When I was in college, I didn't appreciate how much money was invested in the necessary lab equipment. Now that you know what you know, you go back to a lab research situation you're like 'Oh, My God, I could use all this,' and so that was really cool to get to explore and have that freedom and autonomy within a reasonable amount to be able to explore things."

They shared their thoughts on the summer campus experience overall.

- "Overall it was a really cool learning experience. It flew by too. I liked that we were busy a lot."

They then reflected on the reason they didn't take the demonstrations or waste disposal elective courses. They discussed their current experience with waste disposal and how they would have liked the opportunity to gain more knowledge in these areas. Gaining KoSc within the context of waste disposal would expand Taylor's PCK.

- “To be honest, I didn't know [about these courses]. It wasn't a conscious decision that I thought. Had I known what I know now, I think I would have taken them…I've wanted to know better methods for waste disposal for a long time because one of the teachers that I teach with is in his like 24th year, and he's more the guy that's like, ‘well, I'll just flush it with enough water and it's good to go.’ That’s basically been instilled in me, but I'm a lot more cautious than he is with those things, and I'd like to be able to gain the knowledge to be more conscientious of what we're producing, and then how we dispose of it. Then Demos, who doesn't like demos? I would have loved to see more opportunities for demos.”

On the other hand, they enjoyed having the free time in the evenings that would have been taken up by the elective courses.

- “I also really enjoyed the fact that when five o'clock hit during the summer, I didn't have anything that I had to be at the rest of the night, whereas some people would have a six o'clock and then they'd have a six forty-five, and then they wouldn't get home til like seven thirty. I was wiped by the time five o'clock hit because you're just mentally exhausted by the end of the day.”

They then discussed potentially taking one of these elective courses during their second summer on campus, stating that they heard “good feedback” about both courses.

- “I think I would have taken one of them not two, and maybe split them between the summers. If I had to choose, next summer I'll probably end up taking the demos class, but I heard good feedback from all of them.”

Taylor reflected on the value of the teacher-initiated study groups, stating that they were most helpful during the Fall semesters, which each have two chemistry content courses. Interacting with other MS program participants supported Taylor's development of KoSc and, thus, PCK.

- "I thought to the extent that it can be helpful, I think it was very helpful…I think it's whenever you have those two content classes and the content could be challenging. I definitely think organic and kinetics fit that mode, along with nuclear."

Taylor then discussed the value of obtaining feedback from the study group to support their learning outside of formal course meetings. Again, this statement supports Taylor's development of KoSc – and PCK – through collaborative learning.

- "Because the homework isn't embedded within a program that automatically gives you feedback, there's no way for you to know that by the time you turn it in, 'Hey, am I doing this wrong, or did I misinterpret something?' and so that's kind of our form of feedback. Now, we could just ask Instructor A, but that's set on a particular day at a particular time which not everybody can make. And also it's nice to have that idea of certainty prior to the optional meeting with them because then, if there are disagreements and they don't get resolved, you can go in with specific questions."

Taylor reflected that some teaching changes resulting from their experience in the MS program may not occur until they reach certain points in their curriculum.

- "I think it's going to be more about when we get to those things."

Finally, Taylor reflected on the upcoming semester, including preparing for the execution of their action research project and eventual defense.

- "This is going to definitely be a busy semester. Even though I know I'll have to defend late spring or in the summer, I actually think that'll be much easier than the process that I'm going through right now of developing the research and executing the research. By the time I'm ready to defend, I'll know it so well."

<u>Summary of Reflection</u>

In their fourth check-in interview, Taylor reflected on their experience in the MS program. The main themes for reflection were:

- Taylor discussed the value of applying ideas from the literature and working with new instrumentation during CHEM 776, things they may not have done without the opportunities granted by the MS program. These improvements to Taylor's KoSc indicated improvements to their overall PCK.
- In Summer 1, Taylor did not participate in the chemical demonstrations or waste disposal elective courses due to a perceived lack of communication. However, they expressed interest in gaining knowledge related to demonstrations and waste disposal methods in the future. This indicates their desire to improve their KoSc in the future, which would improve their overall PCK.
- The teacher-initiated study groups allowed Taylor to receive feedback from peers on their work and support their learning during content-heavy semesters. Collaborating with other MS program participants supported Taylor's development of KoSc and, thus, PCK.

- Taylor reflected on the second half of their MS program experience, focusing on their preparation, execution, and defense of their action research project.

Codebook 3

Taylor shared five comments coded as "Feedback." These statements were further analyzed using Codebook 3. These coding frequencies are shown in Table 88 below.

Table 88. Check-in Interview 4 Coding Frequencies – CB3

Code	**Abbreviation**	**Frequency of Responses (N = 5)**	**Percentage of Total Responses (%)**
Program Feedback	PF	1	20
Logistical Feedback	LF	4	80

Program Feedback

While Taylor stated that they haven't had concerns about the MS program, they did express their appreciation for the being exposed to more content than pedagogy in MS program courses.

- "I haven't had really any concerns about [the MS program]. I like the pedagogy. I like the amount of pedagogical to content ratio that we do. I like that. The content is a higher number in that ratio than the pedagogical stuff."

Logistical Feedback

Feedback from other MS program participants related to the shift in the Summer 1 schedule due to the Juneteenth holiday. When asked about the schedule shift, Taylor shared positive feedback and did not express any logistical concerns about the new schedule.

- “If I remember correctly, we treated Saturday like it was a normal workday and then we had Sunday off. To be totally honest with you, I actually liked it because I never felt like, ‘Oh, my God! I just need a day to catch up on stuff.’ When we had Sunday downtime, most of the time that we spent wasn't even school-related, which told me that I wasn't so backed up with stuff that I needed to have a day to catch up. I liked it. It definitely made the time go by and I liked being busy.”

When asked about their decision not to enroll in the demonstrations or waste disposal summer elective courses, Taylor stated that they weren’t aware of these courses. They shared their thought process for summer registration, stating that they weren’t aware of various options related to summer courses.

- “To be honest, I didn't know. It wasn't a conscious decision. Had I known what I know now, I think I would have taken them. I didn't know what they were, and that's not anybody's fault, really, but my own because I could have asked more about it. I also didn't know that you could take those credits and apply them to your overall credits to potentially substitute for a class. I didn't know that was an option and so I just did the thing that was classic me: just tell me what to do to complete the program, and then I'll sign up for that. And so I signed up for the summer thing that everybody did 777 and [776], I think. And then that was that, and I just didn't give much thought to anything else. Looking back, I would have.”

Taylor discussed the exhaustion caused by the general schedule of the on-campus summer session. They then shared their ideas for Summer 2 based on their observations of their peers and peer feedback.

- "I also really enjoyed the fact that when five o'clock hit during the summer, I didn't have anything that I had to be at the rest of the night, whereas some people wouldn't get home 'til like seven thirty. I was wiped by the time five o'clock hit because you're just mentally exhausted by the end of the day. I think I would have taken one of them, not two, and maybe split them between the summers, and if I had to choose, next summer I'll probably end up taking the demos class, but I heard good feedback from all of them, so that was cool."

Taylor then shared general feedback about the MS program. They discussed their desire for more logistical uniformity between MS program courses in terms of homework assignments. They expressed their understanding that each instructor may choose to do things differently, but they offered feedback to make the MS program courses more uniform and efficient.

- "It deals more with uniformity. Uniformity can be a double-edged sword because on one hand I get it and the other hand from a teacher's point of view it's like, 'Okay, get out of my face. I don't need to be like everybody else,' but it's nothing to do with the teaching. It's more about the logistical things. I really like the OWL program that we used [in CHEM 772] because of the immediate feedback that it gave. It was a great learning tool from a homework point of view. And then, while simultaneously in another class, I'd be doing homework on a piece of paper. In the grand scheme of things, it's not a big deal, but one of the programs gives me immediate feedback and it's more efficient. My learning is more efficient in that [online homework] program than alternatively. It would be nice if there was more uniformity. I know it's hard with software. It costs money, but there's only a small number of classes within the entire [MS program]. It would be nice not to do homework in one class a particular way, and then do homework in another class in a completely different way. We already have busy lives, so it helps organize things and keeps things less scrambled. It's like, 'Oh, wait! I do homework like this in in 774. I gotta find my papers," whereas you know, in 775 or in [CHEM 772], be like, 'Ok, let me look back at the entropy problems that I did, and I they're on the computer.' But, you know, to each their own sort of thing. I'm just saying from an efficiency point of view."

Codebook 4

Codebook 4 was used to demonstrate the motivations behind Taylor's comments. These coding frequencies are shown in Table 89 below.

Table 89. Check-in Interview 4 Coding Frequencies – CB4

Code	**Abbreviation**	**Frequency of Responses (*N* = 29)**	**Percentage of Total Responses (%)**
Learning-focused	L-f	17	58.6
Student-focused	S-f	2	6.9

Teaching-focused	T-f	10	34.5

Taylor’s comments in their fourth check-in interview included all three motivations. Most of their comments were focused on their own learning that occurred in the MS program (58.6%). They also included comments motivated by their teaching (34.5%) and their students (6.9%). An example of each code is given below.

- “I just learned a whole bunch of chemistry techniques on things that I was aware of but didn't know exactly how to do.” (L-f)
- “The experience this summer has also gotten me to try to be more inquisitive about finding ways to integrate more lab experiences into the classroom.” (T-f)
- “It's kind of funny how being a student again, especially in an online environment, you start to have developed more empathy for your own students.” (S-f)

Summary of Check-in Interview 4

Taylor reflected on their two-week summer campus experience – and their first year in the MS program overall – and shared their goals for Semester 3. Most of Taylor’s comments related to what they learned in the MS program (58.6%). About a third of their comments were motivated by the MS program’s impacts on their teaching (34.5%), while two of their comments discussed implications for their students’ learning. The main themes from Check-in Interview 4 were:

- Taylor gained content knowledge and ideas through the MS program that they applied to their teaching, including their laboratory instruction. They described goals to continue learning chemistry content in Fall 2022 that they could bring into their teaching, especially due to the implementation of new state science standards. These statements demonstrated the combination of their KoSc, KoCO, and KoT, revealing improvements to the quality of their PCK.

- Taylor reflected on their participation in teacher-initiated study groups, through which they received informal feedback on their chemistry work and formed connections with fellow MS program participants. Learning in community with one another supported positive PCK change. They also described the value of meeting fellow MS program participants in person during the summer campus experience, especially those they had already met via Zoom.
- The CoRe and Teaching script modules positively impacted their approach toward teaching by allowing for more reflection in their lesson/unit planning process, connecting to their KoCO and KoT, which indicated improved PCK quality.
- By participating in the MS program, Taylor gained more empathy for their students by being a student themselves, especially related to the time commitment of completing assignments and test anxiety. These comments also demonstrated their KoSt, which indicated improved PCK.
- Taylor outlined their goals for the preparation, execution, and defense of their action research project.
- Taylor shared feedback regarding the schedule for the on-campus summer session. They also discussed experiences with implications for the MS program's communication regarding course registration. They again reiterated their desire for more uniformity between MS program courses.

CoRe

In Fall 2022, the CoRe was administered in CHEM 775: Organic & Biochemistry. The CoRe was analyzed using Codebook 2 to assess participants' PCK. Table 90 displays the codes from Codebook 2 that appeared in Taylor's Semester 3 CoRe.

Table 90. CoRe Coding Frequencies for Semester 3 – CB2

Code	**Abbreviation**	**Frequency of Responses (*N* = 34)**	**Percentage of Total Responses (%)**
Knowledge of science	KoSc	7	20.6
Knowledge of goals	KoG	4	11.8
Knowledge of students	KoSt	10	29.4
Knowledge of curriculum organization	KoCO	2	5.9
Knowledge of teaching	KoT	6	17.6
Knowledge of assessment	KoA	3	8.8
Knowledge of resources	KoR	2	5.9

<u>KoSc</u>

The first component of PCK represented in the CoRe is KoSc, which includes science content, scientific practice, the nature of science, and scientific progress.[41] Taylor first discussed their topic choice of “the process of esterification – conversion of carboxylic acids to esters under acidic conditions.” They then provided learning objectives for the lab activity component of the lesson.

- “To frame the development of the concept of esterification, students will be reacting salicylic acid with excess methanol to produce methyl salicylate and water.”
- “For this lab, students will get to explore how reaction conditions can influence the yield of product.”

Taylor shared the main concepts that they expected students to learn during their CoRe lesson. By connecting their KoSc and KoCO, Taylor demonstrated improved PCK quality.

- “Products formed when a carboxylic acid reacts with an alcohol; role of the acid catalyst in esterification reactions; basic steps involved in the mechanism for esterification; methods for increase the yield of product, more specifically, how to drive the reaction to the right; application of common concepts applied in many organic reactions such as electrophile, nucleophile, proton transfer, and leaving group.”

Taylor shared their additional chemistry content knowledge related to esterification.

- “Cyclic esters can also be formed under these conditions, known as lactones. The mechanism for this reaction is Protonation-Addition-Deprotonation-Protonation-

Elimination-Deprotonation (PADPED). The reaction can be run in the reverse direction by treating the excess ester with excess water in the presence of acid (ester hydrolysis). Fisher esterification is an example of nucleophilic acyl substitution."

When considering difficulties or limitations associated with their chosen topic, they discussed the nature of the content.

- "This is just one example of an organic reaction mechanism, so it's naturally limited with respect to all the other organic reactions out there."

Summary of KoSc

Through their creation of a CoRe, Taylor shared their KoSc through their explanations of esterification and organic chemistry mechanisms. The main themes for KoSc were:

- Taylor demonstrated their KoSc by outlining the intended learning outcomes for students for this lesson, as well as their additional organic chemistry content knowledge.
- Taylor was able to state their goals for student learning, connecting their KoSc and KoCO, which demonstrated improved PCK quality.

KoG

The next code for the CoRe assignment relates to KoG, which may include learning goals for scientific literacy, real-life application, and integrated understanding.[41] Taylor demonstrated their KoG by identifying real-world connections to organic chemistry.

- "Organic reactions such as this are prevalent in many areas of daily life."

- "Understanding how synthetic smells/flavors can be produced to mimic natural smells/flavors."

They also discussed the relevance of these concepts to students' future careers or education. By combining their KoG and KoSt, Taylor demonstrated improved PCK quality.

- "Finding ways to increase the yield of a product is relevant for all kinds of reactions done at the industrial level."
- "Many of my students will attend college and a decent amount of them will experience organic chem at some point. Having some experience with certain organic reactions and how they can be manipulated to produce more product can provide a solid foundation for future success in organic chem."

<u>Summary of KoG</u>

Taylor demonstrated their KoG through the following themes:

- They were able to identify examples of organic chemistry in their students' daily lives.
- They discussed the relevance of learning organic chemistry concepts to prepare their students for future careers or science education. By combining their KoG and KoSt, Taylor demonstrated improved PCK quality.

<u>KoSt</u>

The next code is KoSt, which may focus on different learning levels, needs, interests, prior knowledge, ability, learning difficulties, and misconceptions.[41] Taylor chose to teach their CoRe lesson to their Honors Chemistry course. Their reasoning behind their topic choice related to their KoSt, particularly their knowledge of students' thinking. Their reasoning also involved their past KoSc, which they have further developed during the CHEM 775 course. This combination of KoSc and KoSt demonstrated improved PCK quality.

- "I chose this topic because I have always wanted to provide a deeper understanding of this reaction for my students compared to what we currently do. In the past, any esterification reaction we have done has been very 'cookbook' style and even though students enjoy some of the smells that are ultimately produced, their understanding of this reaction is very surface level. Much of my former approach to this lab is due to my own lack of understanding combined with topics that I wasn't sure whether my students were able to fully understand. The really challenging part for me would be to think about how I can properly scaffold this mechanism in ways that don't simply result in me telling them each step. So, I need to find ways to challenge their thinking, but not so much that it results in cognitive overload or complete shutdown due to lack of knowledge."

Taylor shared multiple difficulties or limitations associated with their chosen topic related to their students' prior knowledge and skill.

- "Lack of background knowledge with protonation and deprotonation."
- "Lack of background knowledge for what makes something a good leaving group."
- "Difficulty with application of previously learned ideas surrounding equilibrium, Le Châtelier's principle, acids/bases, and polarity."

They also shared additional knowledge about their students' thinking that informed how they set up their CoRe lesson. This combined their KoSt and KoCO, which demonstrated improved PCK quality.

- "Most students are very algorithmic in their thinking process. They want to just know something simple like, 'carboxylic acid plus alcohol produces an ester.'"
- "Since they have yet to learn about various organic mechanisms, it's unlikely for them to intuit various steps throughout the mechanism. Therefore, there will need to be considerable guidance throughout each step."
- "Due to lack of background knowledge, students will benefit from sufficient 'chunking' of information throughout their understanding of each step in the mechanism."

When discussing factors influencing their teaching, Taylor took into account the level of their students' lab skills.

- "Lab skills at this level are still very primitive. There needs to be attention to detail when it comes to measurement, observations, and carrying out a reaction in general."

<u>Summary of KoSt</u>

Taylor discussed how their KoSt informed their teaching choices for their chosen topic. The main themes for KoSt were:

- The lab activity used in Taylor's CoRe lesson would allow them to challenge their students' thinking.

- Taylor demonstrated their awareness of their students' level of prior knowledge and skills, which informed their teaching procedures for their CoRe lesson. This combination of KoSt and KoCO demonstrated improved PCK quality.

KoCO

The next code relates to KoCO, which may relate to state and local standards.[41] Taylor provided a relevant state standard relating to organic chemistry reactions. They also described how their CoRe lesson would help students form connections between previously learned chemistry concepts. By combining their KoSt and KoCO, Taylor demonstrated improved PCK quality.

- "Since this would be taught near the end of the year, it provides a great opportunity to incorporate previously learned topics such as acids/bases, charge, intermolecular forces, and polarity into a topic that is largely unfamiliar to students."

KoT

The next code is KoT, which involves the discussion of teaching methods and activities.[41] First, Taylor shared the teaching procedures they would use when teaching their chosen topic, which included statements of their KoSc as well. By combining their KoSc, KoCO, and KoT, Taylor demonstrated improvements to their PCK quality.

- "Exploring various smells that have been synthetically derived to mimic natural smells. This will be used to stimulate questions students may have regarding how it's possible to replicate molecules that nature produces on its own."
- "Displaying example of esterification reaction to stimulate questioning about what must have occurred for ester to form. In other words, gaining clarity about

what bonds have been broken and formed to result in the ester product. This will provide a basic foundation for the need to explore exactly how this occurs."

- "Having groups share their results via whiteboards to compare/contrast data and add to the overall development of the concept."

One of their teaching procedures related to their KoSt, demonstrating improved PCK quality through a combination of knowledge bases. Taylor discussed their knowledge of students' prior knowledge and how this may result in misconceptions.

- "Having groups use various amounts of alcohol in their reaction. This will result in different data, so they can't simply copy each other. Most importantly, when class data is gathered, students should be able to identify that the more excess alcohol that is present, the greater the yield for the ester will be. Students tend to not have a solid understanding of dynamic processes such as equilibrium. Therefore, I would imagine many students might instead treat it like a limiting reactant problem and propose that only a specific amount of ester will be produced, regardless of how much alcohol was used."

They also described the need for scaffolding for this lesson, demonstrating their KoT.

- "Exploring a reaction that has 6 steps in its mechanism is going to require significant scaffolding at this level."

When reflecting on the factors that influence their teaching of this topic, Taylor shared the need to provide visual material to support student learning due to the nature of the content.

- "Since this is highly conceptual, providing visuals of various processes will be helpful."

Summary of KoT

Taylor shared their teaching procedures for their CoRe lesson on esterification. The main themes for KoT were:

- Taylor outlined multiple teaching procedures for presenting the esterification reaction to their students.
- Taylor discussed the need for scaffolding to support student understanding, demonstrating their KoSt by accounting for their students' prior knowledge. Their combination of KoSt and KoT revealed improved PCK quality.
- Taylor also discussed the need to include visual material to support different learning styles.

KoA

The next code is KoA, which details teachers' knowledge of formal and informal assessments and feedback.[41] Taylor shared their methods of assessing student understand or confusion, including direct questioning about the esterification process. By combining KoSc and KoA, Taylor demonstrated improvements to the quality of their PCK.

- "Asking why the oxygen from the carbonyl group doesn't react, but the –OH does."
- "Asking extension questions such as what they think would happen if no acid was used."
- "Hypothesizing how the ester product would change if different carboxylic acid or alcohol was used."

KoR

The final code in Codebook 2 relates to KoR, which discusses materials and activities that teachers utilize in their classrooms.[41] Taylor was aware of laboratory materials needed for their experiment. They also described a lack of equipment as being a limitation associated with their CoRe lesson.

- "Lacking specific equipment that would help with the removal of water to drive the reaction to the right."

Summary of CoRe Data

Taylor's CoRe lesson revealed their understanding of CHEM 775 topics and described how they would apply this knowledge to their teaching. The main themes from Taylor's Fall 2022 CoRe were:

- While acknowledging weaknesses in their own prior knowledge, Taylor described how the CHEM 775 course has improved their understanding of organic chemistry concepts. Taylor discussed improvements to their teaching effectiveness of these topics as a result of increased KoSc. They shared their goals for student learning and outlined learning objectives, demonstrating their KoSc, KoG, and KoCO, which indicated improved PCK.
- Taylor prepared a CoRe lesson that included appropriate scaffolding to account for students' prior knowledge, combining their KoSt and KoT, which demonstrated improved PCK quality.
- Taylor was aware of how this concept ties into previous course topics (KoCO) and shared multiple methods for assessing student understanding (KoA). These comments revealed Taylor's PCK.

- Taylor's CoRe contained all seven components of PCK and demonstrated the intertwining of these knowledge bases, which indicated improvements to the quality of their PCK.

Module Survey – CoRe

After completing the CoRe assignment, Taylor was invited to complete a survey about their experience creating a CoRe for their topic. The CoRe module survey was coded using Codebooks 1 and 4.

Codebook 1

Coding frequencies for Codebook 1 can be found in Table 91.

Table 91. Module Survey Coding Frequencies for Semester 3 CoRe – CB1

Code	**Abbreviation**	**Frequency of Responses (*N* = 9)**	**Percentage of Total Responses (%)**
Attitudes	A-c	1	11.1
Knowledge	K-c	1	11.1
Skill	S-c	1	11.1
Teaching	T	4	44.4
Reflection	R	2	22.2

Attitudes (A-c)

When asked about their confidence level on a scale of 1 to 6 for teaching their concept, Taylor responded with a score of 5.

Knowledge (K-c)

Taylor discussed gaining knowledge of organic chemistry topics through the CHEM 775 course, which also enabled them to teach esterification. Gaining chemistry content knowledge (KoSc) led to improvements in Taylor's PCK. By combining their KoSc and KoT, Taylor demonstrated improved PCK quality.

- "The content of this course has had a large impact on my CoRe. Without the knowledge I've learned so far, I simply wouldn't even consider a topic like esterification, let alone teach it adequately."

Skill (S-c)

Taylor described how the CoRe allowed them to further develop their pedagogical skill by improving their execution of the lesson. By improving their KoT, Taylor showed improvements to their PCK. By combining their KoSc and KoT, Taylor demonstrated improved PCK quality.

- The CoRe "has allowed me to take something that I had previously done and improve it significantly by incorporating a conceptual understanding of what is taking place."

Teaching

Taylor discussed implementing scaffolds into their CoRe lesson to allow for better understanding of organic chemistry concepts in their Honors Chemistry course. By combining their KoSc and KoT, Taylor demonstrated improved PCK quality.

- "Since I was going to be teaching something at a much deeper level, it was challenging to consider the types of scaffolds I would need to incorporate throughout the learning process. It may seem odd, but I don't usually need to consider significant scaffolds at the Honors Chem level."

- "As mentioned previously, significant scaffolds need to be in place or else there is little to no chance the learning that I intended for will not occur. Since this topic deals with a much deeper dive into material to an extent that I'm not used to, I would feel most comfortable being adequately prepared."

They also described how improving their KoT and KoR would increase their teaching confidence and comfort level with the content. These positive changes would lead to improved PCK quality.

- "I would likely feel more comfortable if I had previously covered topics involving electrophiles and nucleophiles early on when teaching organic chemistry. Additionally, I think I would feel more comfortable if I had access to some kind of animation software that helped communicate the various steps involved throughout the mechanism as opposed to static pictures."

<u>Summary of Teaching</u>

Taylor discussed their teaching of organic chemistry topics with the following themes:

- Taylor planned to use scaffolding strategies in their Honors Chemistry course to make the learning of organic chemistry topics more accessible for their students. By combining their KoSc and KoT, Taylor improved the quality of their PCK and demonstrated potential improvements to their teaching effectiveness.
- By teaching more organic chemistry topics and obtaining more instructional resources, Taylor would feel more confident teaching their chosen concept. These

changes would increase Taylor's KoSc, KoT, and KoR, which would lead to improved PCK.

Reflection

Taylor reflected on their experience creating a CoRe for a CHEM 775 topic.

- "It wasn't so much of a challenge considering I had some previous experience with the topic itself."

The CoRe module gave them an opportunity to reflect on their teaching of an organic chemistry topic and adjust a relevant lab activity to better suit student learning. The CoRe enabled Taylor to further develop their KoT and KoR, which led to improved PCK. Reflecting on their teaching practice allowed Taylor to enhance their teaching effectiveness.

- "It has essentially allowed me to consider what is necessary for turning something that had too much of a 'cookbook' feel into something that's more authentic and meaningful for learning."

Codebook 4

Codebook 4 was used to identify the source of motivation that fueled Taylor's comments. Coding frequencies can be found in Table 92.

Table 92. Module Survey Coding Frequencies for Semester 3 CoRe – CB4

Code	**Abbreviation**	**Frequency of Responses (N = 7)**	**Percentage of Total Responses (%)**
Learning-focused	L-f	2	28.6
Teaching-focused	T-f	5	71.4

Taylor's responses to the CoRe module survey were motivated by their teaching (71.4%) and learning (28.6%). They did not share any statements containing student-focused motivations. An example of each code is given below.

- "Since I was going to be teaching something at a much deeper level, it was challenging to consider the types of scaffolds I would need to incorporate throughout the learning process." (T-f)
- "The content of this course has had a large impact on my CoRe." (L-f)

Summary of Module Survey – CoRe

In the CoRe module survey, Taylor reflected on their experience creating a CoRe for a CHEM 775 topic. Their statements were motivated by their teaching (71.4%) and learning (28.6%). The main themes for their CoRe module survey were:

- The CHEM 775 course supported their learning of CHEM 775 topics and inspired them to teach organic chemistry topics. By combining their KoSc and KoT, Taylor improved the quality of their overall PCK.

- The CoRe module allowed Taylor to reflect on their teaching of an organic chemistry topic and make improvements to their instruction, including the implementation of scaffolding strategies. These changes demonstrate their KoT, KoR, and KoSt by taking into account their students' learning needs, which revealed improved PCK quality.

Teaching Script

In Fall 2022, the Teaching Script was administered in CHEM 774: Kinetics, Nuclear, & Electrochemistry. The Teaching Script was analyzed using Codebook 2 to assess participants' PCK. Table 93 displays the codes from Codebook 2 that appeared in Taylor's Semester 1 Teaching Script.

Table 93. Teaching Script Coding Frequencies for Semester 3 – CB2

Code	**Abbreviation**	**Frequency of Responses (*N* = 49)**	**Percentage of Total Responses (%)**
Knowledge of science	KoSc	20	40.8
Knowledge of goals	KoG	6	12.2
Knowledge of students	KoSt	10	20.4
Knowledge of curriculum organization	KoCO	2	4.1
Knowledge of teaching	KoT	9	18.4

Knowledge of resources	KoR	2	4.1

KoSc

The first component of PCK represented in the Teaching Script is KoSc, which includes science content, scientific practice, the nature of science, and scientific progress.[41] Taylor chose to teach redox reactions and shared the reasoning below for their topic choice. By combining their KoSc and KoCO, Taylor demonstrated improved PCK quality.

- "I chose this as one of the most challenging topics for me to teach partially due to my own lack of experience with teaching redox reactions and the anticipated struggles I would expect to occur in a General Chemistry setting. Also, I've never taught redox at the General Chemistry level before."

Taylor shared their additional knowledge of redox reactions beyond what they would teach to a general chemistry class.

- "Application of redox chemistry to battery technology. This includes basics of a galvanic cell, cell potential, why lithium is used in most batteries that operate common things, and what takes place while their phone recharges."

Taylor described three fundamental components of redo reactions.

- "Understanding basic terminology such as the difference between reduction and oxidation (OIL RIG)."
- "Assigning appropriate oxidation numbers to atoms within a chemical reaction."
- "Writing redox ½ reactions to communicate electron transfer."

When discussing what students need to know about their chosen topic, Taylor combined their KoCO and KoSc by discussing intended learning outcomes for redox reactions, which demonstrated improved PCK quality. Some examples are given below.

- "Reduction refers to an atom/ion that has gained an electron while oxidation refers to an atom/ion that has lost an electron."
- "Galvanic cells function off redox reactions that generate a voltage that can be used to generate work. This voltage within the cell is known as the cell potential."
- "Redox reactions are often broken down into ½ reactions that can serve as a way to communicate what is taking place with the transfer of electrons."

Taylor listed basic assumptions for redox reactions that they would share with their students.

- "Ox[idation] # of any monatomic ion is its charge."
- "Ox[idation] # of any free atom is zero."
- "Ox[idation] # of H is +1 and O is -2."
- "Sum of Ox[idation] # in a neutral molecule is zero."
- "Sum of Ox[idation] # in a polyatomic ion must equal overall charge of ion."

<u>KoG</u>

The next code for the Teaching Script assignment relates to KoG, which may include learning goals for scientific literacy, real-life application, and integrated understanding.[41] When discussing the importance of learning redox reactions, Taylor discussed the real-world applications of the topic to their students' everyday lives.

- "The concept of redox reactions can provide a greater conceptual understanding of various chemical reactions while also making chemistry more applicable to daily life. Whether its learning about how batteries work, combustion reactions that generate heat and electricity, or how redox reactions govern how organisms generate energy, the applications are everywhere."

This topic also allows for the integration of multiple chemistry concepts that have already been presented in the course. By combining their KoG, KoSc, and KoCO, Taylor demonstrated improvements to their PCK quality.

- "An understanding of how redox reactions work can allow for the transfer of knowledge between chemistry topics as well. For example, understanding what happens to the charge of an atom when it gains or loses electrons."

Taylor provided the following real-world connections to their chosen topic.

- "Whether its learning about how batteries work, combustion reactions that generate heat and electricity, or how redox reactions govern how organisms generate energy, the applications are everywhere."

Summary of KoG

Taylor demonstrated their KoG by sharing the importance of learning redox reactions and presenting real-world connections for their chosen topic. The main themes for KoG were:

- Taylor found it important to teach redox reactions due to their real-world applications and the ability to relate this concept to other chemistry topics, which they believed would allow for knowledge transfer.
- Taylor was able to identify multiple real-world connections for redox reactions, which they would present to their students to highlight the relevance of the topic.

By combining their KoSc, KoG, and KoCO, Taylor demonstrated improvements to their PCK quality.

KoSt

The next code is KoSt, which may focus on different learning levels, needs, interests, prior knowledge, ability, learning difficulties, and misconceptions.[41] Taylor chose to teach their Teaching Script lesson to their General Chemistry class consisting mainly of 11th graders. When considering how their students would receive their Teaching Script lesson, Taylor was able to identify multiple misconceptions that may appear during the lesson, demonstrating their knowledge of students' thinking. These descriptions of misconceptions also highlighted Taylor's KoSc. This combination of their KoSt and KoSc demonstrated improved PCK quality.

- "Misconceptions about oxidation numbers: Thinking the oxidation number of an atom literally represents its charge or confusion with how to determine the oxidation number of any atom within a molecule."
- "Misconceptions involving electron transfer: This can involve simple confusion between reduction and oxidation. However, my main area of focus when targeting misconceptions involving electron transfer would be understanding what happens to the charge (and oxidation number) of an atom/ion when electrons are gained or lost. Students often associate gaining electrons with positive charge and vice versa. They tend to think about it in a similar manner to gaining losing money where gaining money would result in a positive balance of funds and losing money a negative balance of funds."
- "Misconceptions with writing balanced redox ½ reactions."

Taylor was also able to anticipate potential student questions related to their chosen topic.

- "Are all chemical reactions redox reactions?"
- "How do we explain what makes one atom more likely to be reduced than another?"
- "How can we predict which atom is more likely to be reduced than another?"

They also described anticipated reactions from students during their instruction on redox reactions. They demonstrated their KoSt by detailing their knowledge of students' thinking and behaviors.

- "I don't anticipate a great deal of struggle with individual skills/concepts associated with this lesson. However, students in Gen Chem are notorious for concrete and algorithmic thinking. Therefore, I anticipate mixed reactions when trying to initially bring ideas together and the application of meaning when confronted with novel situations. For example, being able to correct identify oxidation numbers but then failing to make sense of what that means about what was reduced/oxidized."

They also demonstrated their KoT by describing their ability to address these misconceptions. By combining their KoSt and KoT, Taylor demonstrated improvements to their PCK quality.

- "I also anticipate lots of subtle mistakes to be made due to the tendency of most students to not pay close attention to detail. Whether it's at the symbolic or particulate level, there are several instances where proper notation and subtle changes need to be communicated. These subtle mistakes may initially cause frustration and a feeling of not understanding the material. However, if I can spot these common subtle mistakes early enough, I hope to resolve some of the frustration before it takes over and students develop a sense of wanting to give up."

Connecting back to their KoG, Taylor described students' improved engagement due to the integration of real-world connections. By combining their KoG and KoSt, Taylor demonstrated improvements to their PCK quality.

- "If learning this concept within a context that is applicable, I can imagine many students becoming more engaged. For example, making the connection between redox reactions and batteries might spark interest in some students since they can all relate to something like charging their phones."

Summary of KoSt

Taylor demonstrated their KoSt by identifying potential student misconceptions, questions, and reactions to their Teaching Script lesson. The main themes for KoSt were:

- Taylor was able to identify misconceptions that may arise during their instruction of redox reactions based on prior experiences with students, highlighting their KoSt.
- Similarly, Taylor was able to anticipate student questions or reactions to the content based on prior knowledge of students' thinking or behaviors in class. Taylor's combination of their KoT and KoSt revealed improved PCK quality.
- Taylor was able to describe how introducing real-world examples would improve student engagement. By combining their KoG and KoSt, Taylor demonstrated improvements to their PCK quality.

<u>KoCO</u>

The next code relates to KoCO, which may relate to state and local standards.[41] Taylor provided a relevant state standard for their teaching of redox reactions and explained how this topic fits into their curriculum.

- "In our reactions unit, we cover a variety of different reaction types. In Gen Chem, students generally learn to recognize reaction type and predict products based on pattern recognition (for example, A + BC → AC + B) without an understanding of what takes place at the particle level when some of these reaction types occur. The idea of one atom losing an electron while another gains one shows up in all kinds of topics within chemistry due to the common nature of this process. Since we already teach various reaction types, introducing the concept of redox ties nicely by providing an explanatory model for some of these reaction types."

<u>KoT</u>

The next code is KoT, which involves the discussion of teaching methods and activities.[41] First, teachers were asked to share the teaching procedures related to their chosen lesson.

- "Model building using whiteboards and manipulatives."
- "Group discussion and sharing of ideas."
- "Using evidence to drive conceptual understanding."
- "Online simulations to help visualize abstract processes."

Taylor also discussed their timeline for the lesson. By combining their KoCO and KoT, Taylor demonstrated improvements to their PCK quality.

- "Since I would only be scratching the surface for redox reactions, I would anticipate it taking no more than one week to cover reduction, oxidation, ½ reactions, and oxidation numbers."

Taylor discussed how they would address student misconceptions, including providing students with a list of basic assumptions, which were listed in the KoSc section. This combination of their KoSc and KoT demonstrates improved PCK quality.

- "Determining oxidation numbers can easily be done once a few basic rules/patterns are understood. However, the number of rules may be a bit overwhelming for intro students and may get in the way of being able to consistently determine oxidation numbers. Therefore, I would focus my instruction of oxidation numbers on just a few basic assumptions that will still allow students to work with a great deal of redox reactions."

They demonstrated their knowledge of students' thinking (KoSt) by analyzing their misconceptions and introducing methods for correcting their thinking. They described the need to support students' visualization of this topic. By combining their KoT and KoSt, Taylor demonstrated improved PCK quality.

- "However, my main area of focus when targeting misconceptions involving electron transfer would be understanding what happens to the charge (and oxidation number) of an atom/ion when electrons are gained or lost. Students often associate gaining electrons with positive charge and vice versa. They tend to think about it in a similar manner to gaining losing money where gaining money would result in a positive balance of funds and losing money a negative balance of funds. To address this mode of thinking, I would provide opportunities for students to visualize the loss/gain of electrons, its inherent negative charge, and how the amount of positive/negative charge (p+/e-) dictates overall charge of atom."

They would also provide students with examples via practice problems.

- "The primary thing I would address with this is that charge needs to be conserved. I would give students a variety of examples where the number of electrons lost/gained in each redox ½ reaction is not the same and requires balancing of the equations."

Summary of KoT

Taylor outlined their teaching process related to their Teaching Script lesson and described how they would address possible student misconceptions. The main themes for KoT were:

- Taylor shared the purpose for their chosen teaching procedures, focusing on how these strategies would support student learning.
- Taylor used their KoSc to determine the best methods of enhancing student learning. By combining their KoT and KoSc, Taylor demonstrated improvements to the quality of their overall PCK.
- Taylor adapted their instruction for a general chemistry context, taking into account their KoSt. This combination of their KoT and KoSt indicated improved PCK quality.

KoA

The next code is KoA, which details teachers' knowledge of formal and informal assessments and feedback.[41] Taylor did not explicitly outline any assessment methods in their Teaching Script. However, they did describe how they would address misconceptions, indicating their possession of skills relating to identifying student confusion.

KoR

The final code in Codebook 2 relates to KoR, which discusses materials and activities that teachers utilize in their classrooms.[41] Taylor demonstrated their KoR by providing links to a galvanic cell simulation and a video on lithium-ion batteries.

Summary of Teaching Script Data

Through the Teaching Script module, Taylor demonstrated most PCK bases. The most common themes from Taylor's CHEM 774 Teaching Script were:

- Taylor described how they would teach redox reactions to their general chemistry students (KoT), taking into account potential misconceptions and students' prior knowledge (KoSt). They adapted their instruction to their teaching context by utilizing teaching strategies that would best support student learning. This combination of their KoT and KoSt demonstrated improvements to Taylor's PCK quality. They were also aware of how their chosen topic tied into their existing curriculum (KoCO). This combination of their KoSc and KoCO demonstrated improved PCK quality.
- Taylor demonstrated their KoSc by describing knowledge of redox reactions that they strengthened through the CHEM 774 course. Improvements to their KoSc led to improvements to their overall PCK.
- Taylor's Teaching Script contained all PCK bases except for KoA, which may indicate a gap in their PCK. Their ability to identify misconceptions indicates

their ability to assess student understanding, but they did not explicitly demonstrate their KoA. Their Teaching Script demonstrated improvements to all remaining PCK bases, which demonstrated improved PCK.

Module Survey – Teaching Script

After completing the Teaching Script assignment, Taylor was invited to complete a survey about their experience creating a Teaching Script for their topic. The Teaching Script module survey was coded using Codebooks 1 and 4.

Codebook 1

Coding frequencies for Codebook 1 can be found in Table 94.

Table 94. Module Survey Coding Frequencies for Semester 3 Teaching Script – CB1

Code	**Abbreviation**	**Frequency of Responses (*N* = 10)**	**Percentage of Total Responses (%)**
Attitudes	A-c	1	10
Knowledge	K-p	1	10
	K-c	3	30
Background	B	1	10
Teaching	T	3	30
Reflection	R	1	10

Attitudes (A-c)

When asked about their confidence level on a scale of 1 to 6 for teaching their concept, Taylor responded with a score of 5.

Knowledge (K-p and K-c)

Taylor shared their prior lack of knowledge and discussed how the CHEM 774 course improved their chemistry content knowledge (KoSc), which led to improvements to their overall PCK.

- "Though I had taught bits and pieces of redox reactions before, I was far from a deeper understanding of it all. This course helped improve my understanding of redox reactions drastically."

Taylor stated that their teaching confidence for this topic would increase with increased content understanding of redox reactions. This connected to their goal to support student learning, demonstrating their KoG. This combination of KoSc and KoG indicates potential improvements to the quality of Taylor's PCK after gaining additional content knowledge.

- "I think I would feel more confident if I had a deeper understanding of some of the more common applications of redox reactions."
- "My confidence would increase if I was aware of other opportunities to explore redox reactions in such a way to produce the necessary evidence needed to help [students] initially model the concept."

Summary of Knowledge (K-p and K-c)

Taylor described gaining chemistry content knowledge (KoSc) in the CHEM 774 course, which demonstrated improvements to their overall PCK. They also shared that gaining more KoSc would improve their confidence teaching redox reactions.

Background

In terms of their teaching background, Taylor discussed the challenge of bringing a topic into a new teaching context. They discussed experience with both Honors and general chemistry classes. This exercise allowed them to develop their KoCO as a component of their PCK.

- "However, what did present as a bit of a challenge was how to take something that I had only ever taught at a higher level (Honors chem) and think about how I might alter my approach for a different level of students (gen chem)."

Teaching

Taylor described their comfort level teaching redox reactions to their general chemistry class without preparation. They discussed the importance of integrating scaffolding strategies into their instruction, for which they would need preparation. Improvements to their KoT led to improved PCK.

- "This isn't because of my own understanding of the topic, but rather the necessary moments throughout instruction I would want to have in place for students to process, apply, and share their reasoning. In other words, it would just need to be far more scaffolded for general chemistry and that can only occur with proper preparation beforehand."

The CHEM 774 course impacted their teaching of redox reactions by allowing them to reflect on how they could bring this topic into different course levels. Their combination of KoT and KoCO indicated improved PCK quality.

- The CHEM 774 course has "allowed me to think about new ways in which I could teach this concept to a broader level of chemistry students."

The process of creating a Teaching Script enabled Taylor to reflect on how they would go about teaching redox reactions. They shared their teaching process for this topic, focusing on student reception of the material. By combining their KoT and KoSt, Taylor demonstrated improvemenst to their PCK quality.

- "One way I think [the Teaching Script] has guided my teaching of this concept is by intentionally choosing to use an event, like a reaction, to provide evidence that can be used as a context from which the concept can develop. Instead of just diving right into terms and telling them everything, we actually do something, get their initial thoughts about what's happening, talk about it, and I can help them fill in the gaps present in their understanding."

Summary of Teaching

Taylor discussed the impact of the Teaching Script module and CHEM 774 course on their teaching of redox reactions. The main themes related to teaching were:

- The CHEM 774 course prompted them to reflect on how to teach redox reactions to a wide range of students. Taylor shared their need to implement scaffolding strategies when adapting their instruction of redox reactions to a lower level chemistry class. By combining their KoT and KoCO, Taylor demonstrated improvements to their PCK quality.

- Taylor shared how they would teach redox reactions, focusing on their students' learning. They combined their KoT and KoSt, which indicates improved PCK quality.

Reflection

Taylor reflected that creating a Teaching Script wasn't as challenging due to their prior knowledge of their topic. They were able to reflect on potential student confusion in terms of misconceptions. By demonstrating their KoSt, Taylor revealed improvements to their PCK.

- "It wasn't so much of a challenge considering I had some previous experience with the topic itself…I had to consider more areas for potential confusion to arise and try to establish opportunities to avoid the development of misconceptions."

Codebook 4

Codebook 4 was used to identify the source of motivation that fueled Taylor's comments. Coding frequencies can be found in Table 95.

Table 95. Module Survey Coding Frequencies for Semester 3 Teaching Script – CB4

Code	**Abbreviation**	**Frequency of Responses (N = 10)**	**Percentage of Total Responses (%)**
Learning-focused	L-f	2	20
Student-focused	S-f	4	40

Teaching-focused	T-f	4	40

Taylor’s statements were motivated by their teaching (40%), their students’ learning (40%), and their own learning (20%). An example of each motivation type is given below.

- “One way I think [the Teaching Script] has guided my teaching of this concept is by intentionally choosing to use an event, like a reaction, to provide evidence that can be used as a context from which the concept can develop.” (T-f)
- Scaffolding creates “the necessary moments throughout instruction I would want to have in place for students to process, apply, and share their reasoning.” (S-f)
- “I think I would feel more confident if I had a deeper understanding of some of the more common applications of redox reactions.” (L-f)

Summary of Module Survey – Teaching Script

Taylor’s participation in the CHEM 774 course impacted their Teaching Script by equipping them with new knowledge and skills that would allow them to bring their chosen topic into a new context. Their statements were motivated primarily by their teaching and implications for student learning, but they also described impacts to their own learning. The main themes for the Teaching Script module survey were:

- Although the CHEM 774 course allowed Taylor to gain chemistry content knowledge, they shared that further development of their KoSc would improve their teaching confidence of redox reactions. By gaining KoSc, Taylor improved their overall PCK.

- The Teaching Script module allowed Taylor to reflect on how they could adapt their teaching to a new group of students with the use of scaffolding strategies, demonstrating their focus on supporting student learning. By combining their KoT, KoCO, and KoSt, Taylor demonstrated improvements to their PCK quality.

Teaching Observation 3

Pre-Observation Survey

Upon scheduling the Zoom teaching observation, I sent the pre-observation survey to Taylor by email to complete prior to the observation. The pre-observation survey was coded using Codebooks 1, 2, and 4.

Codebook 1

Codebook 1 coding frequencies are shown in Table 96.

Table 96. Pre-Observation Survey Coding Frequencies for Observation 3 – CB1

Code	**Abbreviation**	**Frequency of Responses (*N* = 10)**	**Percentage of Total Responses (%)**
Attitudes	A-c	2	20
Skill	S-c	1	10
Teaching	T	5	50
Reflection	R	2	20

Attitudes (A-c)

Taylor stated that they felt confident teaching their observed lesson and provided the reasoning below.

- “This is largely because I’ve taught it several times before and I feel confident in my understanding of the content itself.”

They also shared their confidence in their pedagogical skill, particularly in regard to adjusting their instruction based on student needs. Taylor’s discussion of their KoT indicated the presence of their PCK.

- “I feel confident in my ability to adjust as needed.”

Skill (S-c)

In terms of pedagogical skill, Taylor displayed their KoSt by discussing their ability to anticipate misconceptions based on their past teaching. They also discuss their ability to make changes to their instruction to ensure the same issues with student understanding do not occur. By combining their KoSt and KoT, Taylor demonstrated improvements to their PCK quality.

- “I can anticipate potential misconceptions and subtle mistakes I’ve seen students make in the past and this helps ensure my students don’t trip up in similar ways when solving problems related to gases.”

Teaching

The lesson Taylor chose for their third observation related to gas laws. They then shared the learning objective below, demonstrating their KoCO as a component of their PCK.

- “Making sure students understand the various gas laws we had previously developed and how those can be combined to make predictions when a gas undergoes change (combined gas law) or no change (ideal gas law).”

Taylor discussed their considerations when planning this lesson, including taking into account students’ level of understanding (KoSt) and reflecting on how they introduce content (KoT). By combining their KoSt and KoT, Taylor revealed improvements to their PCK quality.

- “Not having a clear idea of where students are at in their understanding meant I needed to be ready to adjust my plan on the fly. If I felt the previous gas laws had been sufficiently understood, I would proceed as normal to the development of combined and ideal gas laws.”

Their second statement also presented their KoG by describing their intentions for the lesson. By combining their KoG and KoT, Taylor demonstrated improved PCK quality.

- “Something that I did slightly different this year was include a brief discussion involving the derivation of the combined and ideal gas laws. When appropriate, I try to avoid simply giving students equations without some context as to why the equation is set up the way it is. Additionally, students tend to struggle comprehending the concept of the universal gas constant (R), so I wanted to provide some insight as to where the possible R values come from and why R has such odd units compared to the other variables.”

<u>Reflection</u>

When discussing how they felt about their observed lesson, Taylor reflected on their lack of awareness of students’ preparation due to being out of school the previous week. This statement demonstrates Taylor's desire to involve their KoSt in their teaching, which reveals the presence of higher quality PCK.

- "Due to having COVID that week, I was out of school. Though students had digital activities to help guide them through gas law development, I don't have a clear picture of where my students are at. As a result, I'll sort of need to adjust based on what I can tell they are comfortable with.

Codebook 2

Codebook 2 coding frequencies can be found in Table 97.

Table 97. Pre-Observation Survey Coding Frequencies for Observation 3 – CB2

Code	**Abbreviation**	**Frequency of Responses (*N* = 11)**	**Percentage of Total Responses (%)**
Knowledge of goals	KoG	1	9.1
Knowledge of students	KoSt	5	45.4
Knowledge of curriculum organization	KoCO	1	9.1
Knowledge of teaching	KoT	4	36.4

Taylor primarily shared their KoSt (45.4%) and KoT (36.4%) when presenting their plan for their observed lesson. They also shared examples of their KoCO and KoG by discussing their teaching choices and the intentions behind these choices.

Taylor demonstrated their KoSt by anticipating how their students would receive this lesson.

- "I expect them to do just fine with this lesson. In this class, their math abilities tend to be a bit higher compared to the average. As a result, I anticipate not having much struggle with identifying variables, doing basic algebra, and typing things in their calculator appropriately."

Codebook 4

Codebook 4 was used to demonstrate the motivations behind the teacher's comments. These coding frequencies are shown in Table 98 below.

Table 98. Pre-Observation Survey Coding Frequencies for Observation 3 – CB4

Code	**Abbreviation**	**Frequency of Responses (N = 12)**	**Percentage of Total Responses (%)**
Learning-focused	L-f	1	8.3
Student-focused	S-f	6	50
Teaching-focused	T-f	5	41.7

Most of Taylor's responses to the pre-observation survey were motivated by their students' learning (50%) or their teaching (41.7%); however, one comment included learning-focused motivations.

Teaching Observation

All teaching observations were conducted via Zoom. During Taylor's third semester in the program, I conducted their third teaching observation to assess their current level of teaching effectiveness and active PCK due to any program impact. During the observation, I took notes guided by the Instruction domain of the Danielson Framework for Teaching Evaluation Instrument.[62] The notes of the teaching observation were then analyzed using Codebook 2. Codebook 2 coding frequencies can be found in Table 99.

Table 99. Observation 3 Coding Frequencies – CB2

Code	**Abbreviation**	**Frequency of Responses (*N* = 49)**	**Percentage of Total Responses (%)**
Knowledge of goals	KoG	5	10.2
Knowledge of curriculum organization	KoCO	4	8.2
Knowledge of teaching	KoT	24	49.0
Knowledge of assessment	KoA	12	24.5

Knowledge of resources	KoR	4	8.2

KoG

Taylor demonstrated their KoG by making multiple real-world connections. They also described the purpose of learning the content, focusing on students' development of skills and knowledge. They communicated to students that this topic will likely reappear in college science courses. By combining their KoG and KoSt, Taylor demonstrated improved PCK quality.

KoCO

During the lesson, Taylor communicated the layout of the lesson, including how it fits into the greater unit. They recalled back to past content to make connections between topics and asked students to recall prior knowledge from earlier in the course. By combining their KoCO and KoSt, Taylor demonstrated higher quality PCK.

KoT

Taylor introduced the lesson with a warm-up activity prompting students to recall prior knowledge of gas laws. They then introduced a new concept through direct instruction, modeling, and a demonstration. They clearly communicated student objectives and adapted their instruction based on their evaluation of student understanding. Similarly, they paused their instruction to address student questions. They used key vocabulary when discussing gas law relationships. They encouraged student participation throughout the lesson. They also demonstrated their flexibility by making changes based on student interest or unforeseen issues with materials. By combining their KoT, KoSt, and KoA, Taylor demonstrated the presence of higher quality PCK.

KoA

Through direct questioning, Taylor both assessed their students' retention of prior knowledge and understanding of newly introduced content. When discussing gas law relationships, Taylor asked multiple students for responses, including student participation in their instruction. When receiving a student answer, they probed for deeper understanding. Throughout their direct instruction, they checked for understanding and gave students opportunities to ask questions before moving forward. When students were working independently, they walked around the room to monitor student progress and answered questions when prompted. By combining their KoSt and KoA, Taylor revealed the presence of higher quality PCK.

KoR

Taylor integrated the use of multiple resources in their lesson of gas laws. They used multiple visual models to support their instruction, including one drawn on the board in response to a student question. They conducted a demonstration and referenced an additional demonstration they planned to do the following week. They also discussed with students the use of an online graphing calculator.

Post-Observation Survey

Once I was notified that the Zoom observation was complete, I sent Taylor the post-observation survey by email. The post-observation survey was coded using Codebooks 1, 2, and 4.

Codebook 1

Codebook 1 coding frequencies are shown in Table 100.

Table 100. Post-Observation Survey Coding Frequencies for Observation 3 – CB1

Code	**Abbreviation**	**Frequency of Responses (N = 9)**	**Percentage of Total Responses (%)**
Attitudes	A-c	2	22.2
Teaching	T	4	44.4
Reflection	R	3	33.3

<u>Attitudes (A-c)</u>

Taylor described that they were confident that some learning occurred during the previous week due to students' understanding of those topics; however, they stated that they were not confident that meaningful learning took place during the observed lesson because there had not been opportunities for students to apply these new concepts. This demonstrates Taylor's KoSt, KoT, and KoA, which reveal the presence of higher quality PCK.

- "Their ability to demonstrate successful recall of the gas relationships, equations, and graphs gave me confidence that they had understood the models developed throughout the investigations that week."
- "Though I took some time to develop the combined and ideal gas laws, I'm not yet confident that meaningful learning took place in relation to the application of these new ideas."

<u>Teaching</u>

Taylor described their evaluation of student learning that occurred as they taught their observed lesson, connecting to their KoSt and KoA, which revealed higher quality PCK.

- "Practically each time I asked for some kind of prediction, like in the vacuum chamber, I heard multiple people doing so successfully."

<u>Reflection</u>

Taylor reflected on their lack of confidence that meaningful learning had taken place.

- "This is largely due to the fact that I have yet to give them opportunities to demonstrate their understanding of these new models."

Reflecting on their teaching of the observed lesson, Taylor discussed how they approached the lesson due to their lack of what learning had taken place while they were out of the classroom. This demonstrates Taylor's inclusion of their KoSt and KoA in their teaching, which reveals higher quality PCK.

- "Since this was my first day back after being isolated with COVID, I wasn't entirely sure what to expect since I didn't exactly know the extent to which they had completed things throughout the week. So, I sort of went into it with the mentality of summarizing and applying what should have been learned throughout the week and if time remained, develop combined and ideal gas law. I was able to accomplish these things, but I also felt that introduction to the ideal gas law was rushed due to time and I intend to give that concept much more focus next week."

Taylor then thought about whether or not they would repeat their observed lesson in the future without making any changes. In terms of changes they would make, Taylor discussed integrating opportunities for students to apply their knowledge and for themselves to assess student learning. By discussing their desire to apply their KoSt and KoA, Taylor demonstrated higher quality PCK.

- "How I chose to approach summarizing concepts covered previously that week—yes. When it came to the intro to combined and ideal gas laws—no. This is largely because I didn't quite know what to expect from them going into the day so my plan with this part of the lesson was far less organized and intentional than what I would normally do. I would build in time for application of these new ideas and try to gather some form of evidence of understanding."

Summary of Reflection

Taylor reflected on their observed lesson, sharing the following themes:

- Due to being out of the classroom for a week due to illness, Taylor was unable to evaluate student understanding in their typical manner. However, they were able to assess student understanding throughout the observed lesson. These comments related to their KoA and KoT as components of their PCK, as Taylor reflected on how they accomplished their goals for this lesson.
- Taylor described the need to provide students with opportunities to apply the content and demonstrate their understanding, also connecting to their KoA. This focus on their KoSt, KoT, and KoA demonstrated the presence of higher quality PCK.

Codebook 2

Codebook 2 coding frequencies can be found in Table 101.

Table 101. Post-Observation Survey Coding Frequencies for Observation 3 – CB2

Code	**Abbreviation**	**Frequency of Responses (*N* = 15)**	**Percentage of Total Responses (%)**
KoSt	KoSt	5	33.3
Knowledge of curriculum organization	KoCO	1	6.7
Knowledge of teaching	KoT	5	33.3
Knowledge of assessment	KoA	4	26.7

When reflecting on their observed lesson, Taylor demonstrated four components of PCK: KoSt, KoCO, KoT, and KoA. When discussing whether or not their students understood the material, Taylor demonstrated their KoSt and KoA by discussing how they evaluated students' understanding, which revealed higher quality PCK. In order for them to assess student understanding, Taylor felt that students would need to demonstrate their ability to apply concepts.

- “Though my answer is based on informal evidence, the extent to which I could identify engagement through participation and willingness to provide answers that were also largely accurate tells me they understood the material.”
- “Again, when it came to combined and ideal gas laws, I think they were fine with the equations themselves since their math skills are generally quite good. However, I can’t know for sure if they understood these new ideas yet since there wasn’t time specifically built in for them to apply the ideas. I think their understanding of these new ideas is very surface level at this point.”

Taylor also shared their KoSt and KoT by discussing moments of confusion that occurred during their observed lesson. They described student participation during class, which exposed points of confusion.

- “One moment involved confusion surrounding the concept of inversely proportional and what the corresponding graph looks like. This was a question proposed by a student. It was actually a really good question and gave me an opportunity to clarify some graphical ideas.”
- “Another involved confusion about how pressure could remain constant when discussing the V vs T relationship. Again, this was brought up by a student. When addressing this, nearly most of the class, including that student, had showed some kind of sign that they understood how pressure could remain constant if the container expanded or contracted due to a temp change.”

Codebook 4

Codebook 4 was used to demonstrate the motivations behind the teacher’s comments. These coding frequencies are shown in Table 102 below.

Table 102. Post-Observation Survey Coding Frequencies for Observation 3 – CB4

Code	**Abbreviation**	**Frequency of Responses (*N* = 11)**	**Percentage of Total Responses (%)**
Student-focused	S-f	5	45.5
Teaching-focused	T-f	6	54.5

Taylor's responses to the post-observation survey were motivated by their teaching (54.5%) and their students' learning (45.5%). They did not include any comments about their own learning.

<u>Summary of Observation 3</u>

Taylor's third progress observation focused on gas law relationships, including the introduction of the combined and ideal gas laws. The main themes from Observation 3 were:

- Before the lesson, Taylor expressed their confidence toward adjusting their instruction as needed based on their knowledge of potential misconceptions. During the lesson, they introduced new models separate from their planned instruction to address student questions. Taylor demonstrated flexibility and their ability to adapt depending on student needs, which combined their KoSt and KoT and revealed higher quality PCK.

- Taylor structured their lesson to allow for the "recall" of prior knowledge as well as the introduction of new concepts. Taylor executed their plan to discuss "the derivation of the combined and ideal gas laws," but stated that they are not yet confident that meaningful learning took place. After the lesson, they planned to give students more opportunities to apply their knowledge of gas laws. By combining their KoSc, KoSt, KoT, and KoA, Taylor demonstrated the presence of higher quality PCK.
- Taylor integrated student participation into their instruction, which allowed for the collection of "informal evidence" of student understanding (KoA). They informally assessed student retention of prior knowledge, as well as students' understanding of new concepts, which demonstrated their KoA as a component of their PCK.
- They demonstrated their KoG by bringing multiple real-world examples into their instruction, making the content more relevant for students. They also accomplished this through the use of models and a demonstration (KoR). By combining their KoG, KoSt, and KoR, Taylor revealed higher quality PCK.
- Taylor made connections to content from earlier in the course, revealing the presence of their KoCO as a component of their PCK. They also communicated the layout of the lesson to their students, elaborating on how the observed lesson ties into the rest of the unit.
- Through the observed lesson and its surveys, Taylor demonstrated all seven components of PCK.

Taylor's comments before and after the lesson were mostly split between teaching-focused (47.8%) and student-focused (47.8%) motivations, with one statement being motivated by their own learning.

Check-in Interview 5

At the end of Semester 3, I interviewed Taylor via Zoom to learn more about their experience during their third semester in the MS program. The fifth check-in interview was coded using Codebooks 1, 3 and 4.

Codebook 1

Codebook 1 coding frequencies are shown in Table 103.

Table 103. Check-in Interview 5 Coding Frequencies – CB1

Code	**Abbreviation**	**Frequency of Responses (N = 35)**	**Percentage of Total Responses (%)**
Attitudes	A-p	1	2.9
	A-c	3	8.6
Skill	S-c	2	5.7
Goals	G	4	11.4
Experience	E	2	5.7
Feedback	F	11	31.4
Teaching	T	5	14.3
Interaction	I	2	5.7
Reflection	R	5	14.3

Attitudes (A-p and A-c)

Taylor first reflected on their attitudes toward making changes to their teaching practice. They described their flexibility and explained what they qualify as a justifiable change to their teaching approach. These statements were also coded as reflection.

- "I might be wrong on this, but I don't think it's difficult at all for me [to make changes to their teaching] only because I've always been very flexible. As long as there is adequate justification for me to integrate something, I feel like I've always been super flexible with it. If I'm being told to do something without sufficient evidence or sufficient reasoning, then that doesn't go well for me. But if I can see the underlying rationale for why this makes sense, or why this might be an improvement upon what I had been traditionally doing, then I'm pretty sure I don't have any issue with it."

At the beginning of their teaching career, Taylor described the necessity of being flexible – or being willing to try new things – due to a lack of knowledge and resources. This also indicates lower initial PCK due to low KoT and KoR.

- "At the beginning you have and you know less stuff, like you physically have less [sic] materials and resources because you haven't made them yet or haven't been exposed to them yet and you also just happen to know less stuff, so I feel like you almost can't help but be more flexible. And maybe flexibility isn't the right word. It's more like willingness to try."

After ten years of teaching, Taylor described gaining more knowledge and resources, which added inflexibility with their desire to change their approach; however, they maintained that they still held the same mindset of being willing to make justifiable changes. By gaining resources, Taylor indicated an increase to their KoR – and PCK – by gaining teaching experience.

- "Whereas now, like ten years later, I have stuff already made, and so I always have to evaluate and contrast the new thing with both my prior experiences and the stuff that I have or have been thinking about. That's always going to add a degree of inflexibility to it, but that doesn't mean that I'm not flexible with it. Overall, I think my mindset is the same. I'm willing to try new things just like I was at the beginning as long as I feel as though they are justified, or it's communicated to me in such a way that convinces me that it's justified."

<u>Summary of Attitudes (A-p and A-c)</u>

Taylor expounded on their willingness to make changes to how they teach. They discussed being willing to try new things at the start of their career due to a lack of knowledge, resources, and experience. After ten years of teaching, Taylor maintained a mindset of flexibility; however, they stated that gaining experience and resources made them less likely to make changes unless they were justifiable. From Taylor's perspective, a justifiable change requires "sufficient evidence or sufficient reasoning" that the change would improve their current teaching effectiveness.

<u>Skill (S-c)</u>

Taylor again discussed their struggle with time management, which they hoped to improve upon as they move forward with their professional development.

- "I really need to be disciplined with how I'm managing my time and what I need to get done. That's something I've always struggled with because I feel like I'm always pulled in 87 different directions…It's a skillset that I know I need to always continue to work on."

Goals

Taylor discussed their goals for the remainder of their time in the MS program. They first outlined general goals for completing the MS degree.

- "Do what I got to do this fall. Do what I got to do in the spring. Defend in the summer and then be done with it by next summer of 2023, so that's the ultimate goal."

They then provided three main goals for the rest of their experience in the MS program. The first goals related to the summer laboratory development course. Taylor hoped to gain KoR during their second summer on campus that they could bring back to their own teaching. They expressed their KoG by describing scientific practices that they assist students in developing and KoCO by reflecting on their school's guidelines for student learning. Taylor demonstrated their current level of PCK and indicated their desire to continue improving their PCK.

- "One of them is specific to next summer. I didn't really know what to expect during my two weeks there and I had such a positive experience there and learned so much and got to do so much, especially in the lab. I'd really like to come away with either additional labs that I either haven't done or vastly improved labs as a consequence of being able to run some experiments, see what it's like to perform these experiments in a place where I have access to more resources, like at the college. I'd like to walk away from the program, being like, 'look because of this program I have a set of improved labs that I feel really good about because those provide some of the necessary experiences that are going in the direction of what we're trying to do as a school to reflect more of the science practices that we're trying to build conceptual understanding, so they're not just confirmation labs.' That's one thing that I'd like to physically take away from it."

Their second goal related to developing more relationships with other MS program participants, with whom they could collaborate in the future. This statement was also coded as "Interactions."

- "This is already happening but establish more relationships with different teachers around the country to collaborate with and share with. In addition to the ones that I already have, just continuing to build on that."

Their third goal related to their development of research skills that would enable them to conduct research in their classroom to evaluate their own teaching. This goal would be met through executing their MS action research project, with the resulting skillset having a large potential impact on their future teaching.

- "I really, really, really want to do my research and do it well, and not just be 80% involved in it and just be very intentional about 'Okay, I'm really trying to find this thing out,' because I'd like to be able to take the set of skills that I learn and apply from the action research stuff, so that if I have another type of idea that I think about on my own in the future I can go about it in a similar way to be able to test to see if a particular teaching practice is more useful than another."

<u>Summary of Goals</u>

Taylor shared three main goals for the remainder of their time in the MS program:

- Learn about or develop new lab activities (KoR) during their second summer on campus to bring back to their classroom.
- Continue developing relationships with other teachers in the MS program and collaborate with them in the future.
- Develop research skills through their action research project in order to evaluate future teaching changes in their own classroom.

Experience

Taylor shared ongoing experiences related to their time in the MS program. They first shared how the semester is going by describing the personal circumstances that coincided with their time in the MS program.

- “The semester is going well. It's definitely been a lot of busier for me than previous semesters. I took kind of a full load like last fall. The fall is always more content-focused it seems like and given the fact that I already wasn't going into it with a lot of background information on kinetics and biochem, organic, that added obviously a level of difficulty to it. And then on top of that, school starting, and then the three-year-old, and my wife being pregnant, dealing with that stuff. All these things meshing together, just trying to navigate that all adds a layer of difficulty. I think overall it's good.”

They then shared statements connecting to the “Interactions” code related to their experience in the teacher-initiated study group. Interacting with other MS program participants supported Taylor’s development of KoSc as a component of their overall PCK.

- "Having that study group helped again. That was one thing we did last fall, and we did not do in the spring, and I kind of missed that. It was cool to see that. I don't know how many people exactly but anywhere from six to ten people meet every Sunday night and that's been really helpful mostly for 774. So that's helped."

<u>Feedback</u>

Taylor shared eleven comments coded as feedback. These statements were further analyzed using Codebook 3, which will be shared in the section below.

<u>Teaching</u>

Taylor shared how the MS program has impacted their instruction. They first discussed an impact of the CHEM 774 course on their recent teaching. They also shared how the KoSc they gained through the MS program impacted their attitudes (A-c) toward teaching the content. This combination of their KoSc and KoT indicated improved PCK quality.

- "I just got done teaching about galvanic cells and redox for really the first time ever in any of my classes and that was primarily because of what I learned about redox and galvanic cells in 774. I felt more comfortable than I had ever been, comfortable enough to teach that stuff, so it's kind of cool to see some of the fruits of the labor."

Taylor stated that they have made more changes to their teaching "more so from the content point of view than the pedagogical point of view," which indicated improved PCK quality through their combination of their KoSc and KoT. They then described new demos and activities that they have brought or hoped to bring into their teaching from their summer campus experience. This combined their KoR and KoT, which indicated higher quality PCK.

- "There were little things like some little demos, not necessarily whole entire experiments yet, [that they brought into their teaching from the MS program]. I really like the fact that we had to come up with labs over the summer while we were there, and then we would do them. There were some labs that I could definitely see myself integrating."

Taylor also described changes to their department's teaching approach that "tie back into the pedagogical" skill they developed in the CHEM 778 course. This application of their KoT to their teaching indicated improved PCK.

- Taylor and their colleagues "have been trying to do a lot more modeling and a lot more emphasis on more of a constructivism type of mindset. We're not just jumping right into the concept and then me doing a lot of the leg work as far as building the concept. We're exposing [students] to experiences and data that is collected throughout that experience to help drive the development of the concept."

Relating to their flexibility with making changes to their teaching, Taylor shared an example of a recent experience in their classroom. Taylor discussed implementing a modeling activity into their instruction that was suggested by their colleague a day prior. This demonstrated improved KoR as a component of their PCK.

- "A colleague came up with what I thought was a really interesting activity for double replacement reactions. You can imagine a nitrate ion that's on a little wooden piece, and it has one little notch, and then that little notch fits into a sodium ion. We had these pictures of beakers, and it was just like, 'Okay, I haven't used those little pieces before, but yes, I've always been an advocate for particle diagrams. This is a nice way for the kids to manipulate the particles, move them around, see which ions combine with which. It's also really helping with balancing.' My larger point was he told me that on a Monday, and then on Tuesday I just 'okay, I'm going to do it.' I just kind of went in headfirst, but that's because it made sense. And so yes, I think I'm very flexible with that stuff."

Summary of Teaching

Taylor discussed their willingness to make changes to their teaching, especially related to knowledge, skills, and resources they gained through the MS program. The main themes related to teaching were:

- Taylor incorporated chemistry content gained in the CHEM 774 course into their teaching, sharing that they were able to bring topics that they'd never taught before into their class due to improved comfort with teaching the content. By developing stronger KoSc, Taylor improved their PCK and was able to teach redox and galvanic cells more effectively.
- Taylor hoped to integrate labs developed during the summer campus experience into their curriculum, demonstrating the impact of the MS program on their KoR.
- Taylor discussed bringing more modeling into their instruction and demonstrated their flexibility with making changes to their teaching by describing a new modeling activity they recently implemented. Because Taylor was willing to make changes, they were more inclined to apply knowledge and resources from the MS program to their teaching.

<u>Interaction</u>

As described in the "Goals" and "Experience" sections above, Taylor discussed their desire to develop relationships with fellow MS program participants as well as interactions that take place through the teacher-initiated study group. These interactions were meaningful to Taylor by providing additional academic and professional support that could extend past their time in the MS program.

<u>Reflection</u>

Taylor then discussed their experiences with their action research project. They described their struggles with the logistical components of the project, including obtaining IRB approval.

- "I need to get over the hump of the logistical stuff. I keep telling myself I still need to get IRB approval. Because I know what I'm going to do, there's not this drive to get the logistical stuff done and out of the way. But then, in the back of my mind, I'm like, 'Yeah, but it needs to get done and out of the way, otherwise you can't do the thing that you already know how to do'…I do think I need to touch base with Instructor B at least once, just for clarification."

They then reflected on their decision to change research topics, thus eliminating their progress. However, they expressed positive attitudes toward their choice to start over.

- "I changed [their research topic] while I was at SDSU. I had the paper written, I had twenty plus pages of stuff, and then I just tossed it all. I'm actually happy that I did do that, but because of that I was not in the same position as necessarily everybody else when we had time at SDSU to work on that particular thing."

Taylor described experiencing more changes to their teaching in terms of content than pedagogy. They then reflected on how the MS program has fulfilled their intention to gain more chemistry content knowledge (KoSc) than pedagogical knowledge (KoT). This improvement to their KoSc led to improved PCK.

- "Overall in the past year and a half I've had a lot more exposure to new content stuff than I have pedagogical stuff. One of the primary motivators for me joining the program in the first place was content focused rather than necessarily looking to improve pedagogical practices. I liked that it was a chemistry focused master's program rather than just educational focused. Obviously, it's a hybrid of both, but it felt more like a 70/30 split of 70 content. And that's what attracted me to it."

Taylor also reflected on the serendipity of their department starting a book club over one of the texts from CHEM 778, which allowed them to further their own professional development in their school setting. They described the benefit of bringing these discussions into their own school so as to directly benefit their students.

- "It just happens to be a coincidence that one of our department members wanted to start a book club, which just so happened to be *Ambitious Science Teaching,* which was our book of choice for [CHEM 778].[72] This is awesome because, as many conversations as we had about that book, at the end of the day you always had this feeling of 'yeah, but I would like to be able to have these types of conversations with the people in my building.' To go into those new conversations, having already had some of the conversations with people around the country in that program, it's going to provide a nice way to bridge that gap and make the connections to our school and our students."

When discussing changes to their teaching resulting from the MS program, they explained why they haven't implemented any significant changes to their teaching yet. They also confirmed that the MS program has impacted their teaching. Thus, the MS program has allowed Taylor to improve their KoSc, KoT, and KoR as components of their overall PCK.

- "And so though I haven't done [labs from CHEM 776] specifically, I think it's partly because it's early on in the year still, and a lot of the stuff that we did go over with acids and bases and kinetics and stuff like that, it's going to come later down the road. But yeah, there's definitely been ways in which [the MS program] has impacted my teaching somehow, someway."

<u>Summary of Reflection</u>

Taylor reflected on how their time in the MS program had impacted their teaching, as well as how they are progressing toward their MS degree. The main themes for reflection were:

- Taylor shared positive thoughts regarding their decision to switch topics for their action research project, which required them to restart their paper. They also described their motivational and logistical struggles for obtaining IRB approval.
- Taylor stated that the MS program has helped them meet their goal of gaining chemistry content knowledge (KoSc), reflecting that they have been exposed to more content than pedagogy through the MS program. By improving their KoSc, Taylor demonstrated improved PCK.
- Through a departmental book club, Taylor was able to discuss *Ambitious Science Teaching* with their colleagues, which gave them more opportunities to bring

ideas from CHEM 778 into their classroom and effect change in their overall department.[72]

- Taylor stated that the MS program has impacted their teaching, even if some changes may not be implemented until later in the school year.

Codebook 3

Taylor shared eleven comments coded as "Feedback." These statements were further analyzed using Codebook 3. These coding frequencies are shown in Table 104 below.

Table 104. Check-in Interview 5 Coding Frequencies – CB3

Code	**Abbreviation**	**Frequency of Responses (*N* = 11)**	**Percentage of Total Responses (%)**
Program Feedback	PF	2	18.2
Course Delivery Feedback	CDF	4	36.4
Logistical Feedback	LF	5	45.5

Program Feedback

Taylor felt that they "for sure" had adequate support throughout the MS program regarding their action research.

- "Being at SDSU, I definitely felt like I had the support both from Instructor B and Instructor A. I was able to meet with [Instructor B] several times one-on-one and talk, and it wasn't super formal. It was just a nice informal, ‘we’re just talking about this, two people who are interested in research.’ That was really nice. That provided a lot of clarity in my own research that I'm intending to do. I definitely feel like I've had support along the way.”

Taylor also expressed the MS program’s fulfillment of their expectation that it would focus on chemistry content.

- “I think it is what I expected in the sense of a larger focus on content, which has been nice.”

<u>Course Delivery Feedback</u>

Taylor shared their thoughts on the general format of MS program courses delivered virtually. They emphasized their preference of required weekly meetings.

- “Certain things are what I expected and certain things aren't. I do like the fact that in certain classes we meet every week. I actually really liked the fact that there was a requirement to meet once a week [in CHEM 778]. I don't necessarily know why I like that more because I still attend the optional one every Wednesday, but there is just something about needing to be there and that we were there for a specific reason to discuss a particular set of things. That provided the underlying motivation to be prepared for whatever we were going to talk about.”

Taylor elaborated that the MS program has mostly met their expectations for virtual course delivery. They described expecting more uniformity in terms of having recorded lectures from their instructors.

- “For the most part it was what I expected because them knowing that we're all teachers it’s not like they're going to expect us to meet every day and we're going to have to attend live lectures because that wouldn't make any practical sense. There are other things that I expected more of that sometimes they do happen in one class, but then they don't happen in another class. For example, recorded lectures from the professor. Some classes offer them, and some classes don't, and so I thought that there would be more uniformity with that where I would be learning from my professor more often. Overall, I expected to have discussion forums. I expected to do homework. I expected to have access to videos. So, for the most part, yeah, it's in alignment with what I anticipated."

Taylor further described the importance of having instruction from their specific instructor to clarify their instructor's expectations for learning.

- "If you are going to teach a virtual class in [the MS program], that also means that you're making an effort to personally teach it. In other words, the things that you want your students to learn are for the most part coming from you. I'll post Khan Academy videos or other videos where I feel like somebody else explained this better than I did, right? So I'm not saying none of that, but if for no other reason than to have that more personalized feel to it. Sometimes you'll read a textbook or you'll hear something in a particular video and because it's not part of your specific class you may be misinterpreting it, or they may do it a slightly different way, and the teacher has a different expectation, and then it gets messy along the way."

They expressed that this feedback is primarily in reference to the CHEM 772 and CHEM 775 courses. They further elaborated on why they would prefer direct instruction from their specific instructor.

- “As far as which classes I’d like to see more [videos from the instructor]? Yeah, so [CHEM 772] and [CHEM 775]. Even with Instructor A, I know it's just them at a whiteboard writing things and talking. I know that they’re recording it, and I'm not physically talking to them. But there's just something to be like, ‘I'm hearing this from you, and I'm hearing how you discuss it, and by hearing that I'm also becoming aware of what your expectations are of how to demonstrate this particular concept.’ There's just something that's nice about that. I feel like research supports that anyway, that kids report that they prefer to learn from their teacher rather than somebody else. I feel like that's true for little kids and learners in general. Like, if you told me that, I’d be like, ‘Okay, maybe I’ll start making my own videos.’”

<u>Logistical Feedback</u>

Taylor commented that they did not prefer SDSU’s learning management system, D2L.

- “I think D2L is not the best learning management system overall, which doesn't say anything about the program necessarily. I get that that's not necessarily in their control.”

Taylor desired more uniformity for how the courses are set up logistically online.

- “I think there are certain things - and we've talked about this before – but the certain lack of uniformity or some standardization in: ‘Where do I go to access Zoom meetings? Where do I go to access the content and the quizzes?’ How we're doing it is different in different classes, and so that is kind of unexpected, but you adapt, and it just is what it is.”

Relating to communication, Taylor emphasized the need for a clear schedule of due dates for each MS program course. However, they recognized that this could be logistically challenging for MS instructors.

- “I would also say a big, big thing that I've talked about with other students who are taking this program is we really, really like it when there's a clear schedule of ‘this is when things are due. This is what we're doing,’ because after a few weeks it just comes in your mind like ‘on Sunday nights this is due, on Wednesday nights this is due,’ and so, intuitively as that particular day approaches you know what to expect. For the most part there is some degree of that in different classes, but just ensuring that whatever you do, that there's a clear set schedule. It would be nice if that schedule was very clearly constructed early on to the degree that it can be. Sometimes I feel like I personally work day to day, and I'm just surviving the next day, so I know it could be a big toll to ask ‘Hey, let's have the whole semester planned,’ but if it's something that you're doing in a virtual setting year to year, I think more and more can be built up to allow you to construct that kind of schedule.”

Taylor appreciated the use of online homework software in CHEM 772 and CHEM 775 due to its immediate feedback, which supported their learning. They would prefer not to have to pay for this service but found it helpful.

- “One of the things I will say about [CHEM 772] and [CHEM 775] that hasn't been true in any of the other classes is I have liked the [homework software] that we've used. They both serve the same function of providing intentional practice that gives you feedback and allows you to learn along the way while you're evaluating your understanding. That is something I wish there was more of in all the classes because the immediacy of it is so nice, that feedback, so that's something I have really enjoyed. I didn't really like the fact that it cost me additional money to purchase it. I feel like I'm already spending thousands of dollars to take this course so that should be thrown in as part of the tuition, or part of my tuition should already go toward that sort of thing, but again it's not like it broke the bank. It was like $42 or whatever, but that was something that I had kind of forgot to mention that I really do like. I think it's been very helpful."

They confirmed that the additional cost of the online homework software would not dissuade them from taking the course. They suggested that the university could offer financial support for teachers who may not be able to pay the fee.

- "If that meant that I pay $80 extra, it wouldn't dissuade me from taking the course. Plus, I think as long as there was some alternative route that 'if this is a struggle for you and you want to have some kind of scholarship money,' it wouldn't be hard for the university to find some money to help support that because the enrollment of people is not so high that you're talking thousands of dollars. I would imagine it'd be just hundreds of dollars which I could imagine they could come up with relatively easily."

Codebook 4

Codebook 4 was used to demonstrate the motivations behind Taylor's comments. These coding frequencies are shown in Table 105 below.

Table 105. Check-in Interview 5 Coding Frequencies – CB4

Code	**Abbreviation**	**Frequency of Responses (*N* = 29)**	**Percentage of Total Responses (%)**
Learning-focused	L-f	16	55.2
Student-focused	S-f	3	10.3
Teaching-focused	T-f	10	34.5

Taylor shared statements primarily motivated by their own learning that took place during the MS program (55.2%). They also shared teaching-focused (34.5%) and student-focused motivations (10.3%). An example for each code is given below.

- "One of the primary motivators for me joining the program in the first place was content-focused rather than necessarily looking to improve pedagogical practices." (L-f)
- "I just got done teaching about galvanic cells and redox for really the first time ever in any of my classes and that was primarily because of what I learned about redox and galvanic cells in 774." (T-f)
- "I've always been an advocate for particle diagrams. This is a nice way for the kids to manipulate the particles, move them around, see which ions combine with which." (S-f)

Summary of Check-in Interview 5

Taylor discussed their experience in Semester 3, while sharing reflections of their first year in the MS program and projections for how their overall experience will impact their teaching in the future. Most of Taylor's comments were motivated by their own learning (55.2%), while approximately one-third of their statements focused on their teaching. They also shared comments on how their experience in the MS program will have a positive impact on student learning (10.3%). The main themes from Check-in Interview 5 were:

- Taylor reflected on their experience in their third semester in the MS program, discussing the stresses related to completing their MS degree while balancing teaching and family life. This experience prompted them to focus on developing stronger time management skills.
- They described their willingness to make changes to their teaching. They reflected that they have always felt flexible making changes to their teaching as long as there is "sufficient evidence" behind the proposed change. Ten years into their career, they indicate greater KoT and KoR, which relate to improved PCK, but maintain their willingness to make reasonable changes to their practice. Thus, Taylor would be willing to make teaching changes due to knowledge, skills, and resources they gained from the MS program, including lab activities developed in CHEM 776 and modeling techniques discussed in CHEM 778.
- Taylor discussed how the MS program has impacted their teaching, with changes focusing primarily on content rather than pedagogy. They reaffirmed their choice to complete the MS degree at SDSU due to its focus on chemistry content. Taylor

was able to make positive changes to their teaching of CHEM 774 topics due to their improved KoSc, which indicates improved PCK.

- Taylor's goals for the remainder of their time in the MS program were: to gain more laboratory resources for their classroom; to gain relationships with other teachers for future collaboration; and to gain research skills that would enable them to perform action research in their own classroom, thus evaluating their teaching effectiveness.
- Taylor's feedback at the end of Semester 3 focused primarily on course delivery and logistics. They appreciated having required Zoom discussions and recorded video lectures from their specific instructor for the course. They emphasized the need for a clear schedule of due dates in MS program courses. They also preferred having an online homework system that could offer immediate feedback, even if this incurred an additional fee.

End-of-Semester Survey

At the end of the Fall 2022 semester, I sent out an email invitation to participants of CHEM 774 and CHEM 775 to complete a survey about their experiences in core MS program courses and the MS program overall during the given semester. Taylor's responses to this survey were coded with Codebooks 1, 3, and 4.

<u>*Codebook 1*</u>

Coding frequencies for Codebook 1 can be found in Table 106.

Table 106. End-of-Semester Survey Coding Frequencies for Semester 3 – CB1

Code	**Abbreviation**	**Frequency of Responses (*N* = 22)**	**Percentage of Total Responses (%)**
Attitudes	A-p	1	4.5
	A-c	2	9.1
Knowledge	K-p	1	4.5
	K-c	6	27.3
Feedback	F	8	36.4
Modules	M	1	4.5
Interaction	I	1	4.5
Reflection	R	2	9.1

Attitudes (A-p and A-c) and Knowledge (K-p and K-c)

Taylor described the impact of the MS program content courses on their chemistry content knowledge and teaching confidence, demonstrating positive attitudes and increased KoSc as a component of their PCK. By combining their KoSc and KoT, Taylor demonstrated improved PCK quality.

- "Both [CHEM 774 and CHEM 775] have increased my content knowledge on topics I wasn't all that comfortable with in the past. Consequently, I feel much more confident in my ability to teach these topics."

Taylor again described the impact of gaining chemistry content knowledge (KoSc) on their teaching confidence. They planned to bring knowledge gained in the MS program into their instruction, demonstrating professional development and improved PCK quality through their combination of KoSc and KoT.

- Their chemistry content knowledge “has improved quite a bit on a variety of topics. Given the lack of knowledge I had coming into this semester related to these topics, I feel much more confident trying to integrate these topics into my curriculum.”

Taylor stated multiple times throughout the end-of-semester survey that the MS program courses positively impacted their content knowledge, leading to improved KoSc as a component of their PCK.

- “I really feel like I'm learning about topics that are at a higher level than I may have originally.”
- “Awareness of access to various external resources helpful to understanding these topics.”
- “Put simply, I have a much better grasp of my own content area.”

Summary of Attitudes (A-p and A-c) and Knowledge (K-p and K-c)

Taylor described how the MS program positively impacted their chemistry content knowledge and their teaching confidence of CHEM 774 and CHEM 775 topics. The main themes for attitudes and knowledge were:

- Taylor described learning more advanced topics than anticipated in the MS program, which led to a stronger content understanding. This improvement to their KoSc indicated improved PCK.
- Taylor felt more confident integrating CHEM 774 and CHEM 775 topics into their instruction as a result of the learning that took place in MS program courses.

This combination of their KoSc and KoT demonstrated improvements to their PCK quality.

Feedback

Taylor shared eight comments coded as feedback. These statements were further analyzed using Codebook 3, which will be shared in the section below.

Modules

The CoRe and Teaching Script modules allowed Taylor to reflect on their teaching and integrate their new knowledge into their instruction. This reflection allowed Taylor to apply new KoSc to their teaching, which indicated improved PCK quality.

- "As a teacher, the Teaching Script and CoRe assignments were most meaningful because of the amount of pedagogical reflection it required and the need to find ways to integrate what we had been learning."

Interaction

Through the MS program, Taylor was able to form professional connections with other MS program participants. These interactions allowed Taylor to further develop their KoT as a component of their PCK.

- "New relationships formed with other teachers. This has allowed me to discuss various things with them related to teaching outside of class."

Reflection

Taylor reflected on their third semester in the MS program, stating that their learning focused more on chemistry content than pedagogy. Thus, the MS program supported greater increases to their KoSc than their KoT as components of their PCK.

- "I really felt like this semester was much more content-heavy for me. As a result, I don't really feel like I learned much more related to my own pedagogy."

Gaining chemistry content knowledge allowed Taylor to reflect on their teaching. This combination of their KoSc and KoT demonstrated improvements to their PCK quality.

- "This has allowed me to think about how I teach various chem topics in ways I may not have even considered before."

Codebook 3

Taylor shared eight comments coded as "Feedback." These statements were further analyzed using Codebook 3. These coding frequencies are shown in Table 107 below.

Table 107. End-of-Semester Survey Coding Frequencies for Semester 3 – CB3

Code	**Abbreviation**	**Frequency of Responses (*N* = 8)**	**Percentage of Total Responses (%)**
Assignment Feedback	AF	1	12.5
Course Feedback	CF	3	37.5
Program Feedback	PF	2	25
Logistical Feedback	LF	2	25

Assignment Feedback

Taylor appreciated getting feedback on homework assignments for the MS program, which supported their learning.

- "The homework was very meaningful to me as a learner due to the degree of feedback received while attempting the assignments."

Course Feedback

Taylor felt that the CHEM 775 readings did not adequately support their learning.

- "As a learner, the readings in 775 weren't very meaningful simply because they lacked detail. I kept finding myself needing to seek out external resources to provide clarity on ideas."

For the CHEM 774 course, they appreciated "personalized" videos, notes, and feedback from the instructor.

- "CHEM 774: There was much more of a personalized feel to this course from the professor. Videos and notes provided were created by the teacher and adequate opportunities for feedback were provided."

For the CHEM 775 course, they felt that the content was not as personalized.

- "CHEM 775: Though I certainly learned a bunch throughout the course, much of it felt very outsourced. Whether it was the assignments, quizzes, or videos, it was usually from some external resource and felt much more like it wouldn't have been much different if it has just been purely an online course."

Program Feedback

Taylor stated that the high level of content in the MS program courses exceeded their expectations.

- "The level of content we are exposed to. I really feel like I'm learning about topics that are at a higher level than I may have originally anticipated, and I like that."

Taylor suggested improvements to the MS program relating to teaching participants video and screencasting skills.

- "One thing that I might add to improve the program is some kind of requirement for teachers to learn about and produce quality videos/screencasts on various topics. One of the skills that many teachers have needed to develop over the past several years is video production and even editing. In addition to certain summaries of topics we do in the program, it could be beneficial to also do videos/screencasts."

Logistical Feedback

Taylor appreciated the use of an online homework program used in CHEM 775, which provided immediate feedback.

- "I especially liked the program Aktiv to complete the homework in CHEM 775 since it would provide instant feedback."

In terms of what has not met their expectations about the MS program this semester, they discussed the lack of logistical consistency between MS program courses.

- "Consistency between classes with respect to logistics. This includes how assignments are completed and how exams are administered."

Codebook 4

Codebook 4 was used to analyze Taylor's motivations for statements made in the end-of-semester survey. Coding frequencies can be found in Table 108.

Table 108. End-of-Semester Survey Coding Frequencies for Semester 3 – CB4

Code	Abbreviation	Frequency of Responses (*N* = 15)	Percentage of Total Responses (%)
Learning-focused	L-f	11	73.3
Teaching-focused	T-f	4	26.7

Taylor’s responses to the end-of-semester survey were primarily motivated by their own learning (73.3%), but also related to their teaching-focused motivations (26.7%). An example of each code is given below.

- “Both [content courses] have increased my content knowledge on topics I wasn't all that comfortable with in the past.” (L-f)
- “I feel much more confident trying to integrate these topics into my curriculum.” (T-f)

Summary of End-of-Semester Survey

In the Fall 2022 end-of-semester survey, Taylor described improvements to their chemistry content knowledge and confidence teaching CHEM 774 and CHEM 775 topics. Their comments were motivated by their learning (73.3%) and teaching (26.7%). The main themes from Taylor’s responses to the end-of-semester survey were:

- Taylor’s participation in MS program courses allowed them to gain chemistry content knowledge, improving their KoSc as a component of their PCK.

- Taylor's increased KoSc led to improved teaching confidence. Their engagement with the CoRe and Teaching Script, as well as discussions with other MS program participants, gave them the opportunity to reflect on their teaching of these topics, which improved their KoT. These improvements to their KoSc and KoT led to improved PCK.
- Teacher shared feedback on MS courses and MS program logistics. They appreciated personalized notes, videos, and feedback from their instructor as opposed to content from external resources. They valued feedback on homework assignments, especially the immediate feedback provided by an online software used in CHEM 775. They appreciated the high level of content they were exposed to in MS program courses. They suggested incorporating video or screencasting production into the MS program requirements and having more consistency across courses.

In Semester 3, Taylor's overall PCK increased due to improvements to their KoSc and KoT.

Summary of Semester 3

During Semester 3, Taylor participated in the fourth check-in interview, the CoRe and its module survey, their third progress observation and its surveys, the Teaching Script and its module survey, the fifth check-in interview, and the end-of-semester survey. The main themes for their third semester in the MS program were:

- Taylor demonstrated all seven components of PCK during their third progress teaching observation. By combining multiple knowledge bases in their reflections before and after their lesson, they demonstrated improvements to the quality of their PCK.

- Taylor gained chemistry content knowledge (KoSc) through the MS program courses, which led to improved teaching confidence. Increases to their KoSc cause improvements to their overall PCK. Furthermore, Taylor applied KoSc gained in the MS program courses to their own instruction (KoT), which evidences improved PCK quality and demonstrates concrete impacts of the MS program on participants' teaching.
- The CoRe and Teaching Script modules allowed for reflection of their teaching of CHEM 774 and CHEM 775 topics, which improved their KoT as a component of their PCK. Their module lessons also focused on student-focused teaching strategies, demonstrating their KoSt, KoG, and KoT as components of their PCK. In both modules, they emphasized the need to employ scaffolding strategies, which relates to their KoT and KoSt as components of their PCK. Although their Teaching Script did not explicitly identify any assessment methods, they demonstrated their KoA as a component of their PCK in the CoRe and other data sources. Their intertwining of knowledge bases in both modules demonstrated improvements to the quality of their overall PCK.
- Discussions with other MS program participants, including the teacher-initiated study groups, supported Taylor's growth of their KoSc and KoT, especially during a semester in which they took two chemistry content courses. These improvements to these knowledge bases indicate improved PCK. The support from fellow teachers helped Taylor to better balance their MS program learning in

the midst of family changes and professional responsibilities. Interactions with other MS program participants had a positive impact on their PCK development.

- Taylor felt that developing research skills through the action research component of the MS program would enable them to conduct research in their classroom, which would allow them to evaluate the effectiveness of their teaching choices.
- Taylor's goals for the remainder of their time in the MS program were to gain more laboratory resources, strengthen connections with other MS program participants for future collaboration, and gain research skills to perform action research in the future. These goals relate to their professional development, indicating their desire to apply knowledge, skills, and experiences from the MS program to their instruction. Based on these goals, the MS program will continue to impact Taylor's teaching after their completion of the degree.
- Taylor's feedback during Semester 3 focused primarily on the organization of MS program content courses, course delivery, and logistics. They appreciated recorded video lectures and course materials from their specific instructor. They valued feedback on assignments, especially immediate feedback provided by the online program used in CHEM 775. They emphasized their desire for more uniformity between courses, as well as clearer communication of course and MS program expectations.

Semester 4

During Semester 4, Taylor participated in one content course. CHEM 773 focused on equilibria and acid-base chemistry topics. This course was fully online and primarily asynchronous. Optional weekly Zoom sessions were the only synchronous components of the course. The data for Semester 4 is presented chronologically. The sixth check-in interview took place via Zoom at the beginning of Semester 4. The CoRe assignment was due at the end of the semester, along with the CoRe module survey. Taylor participated in a progress teaching observation, along with pre- and post-observation surveys, near the end of the semester. The End-of-Semester survey was sent out after the conclusion of the semester. Table 109 discusses the methods used during Semester 4.

Table 109. Semester 4 Data Collection Methods

Term	**Data Collection Methods**	**ID Codes**
Semester 4	**CHEM 773:**	
	CoRe	CoRe
	Module Survey	MS
	General:	
	Check-in Interview 6	I
	Teaching Observation	TO
	End-of-Semester Survey	EOS

Check-in Interview 6

At the beginning of Semester 4, I interviewed Taylor via Zoom to learn more about their overall experience in Semester 3 and their goals for their fourth semester in the MS program. The sixth check-in interview was coded using Codebooks 1, 3 and 4.

<u>Codebook 1</u>

Codebook 1 coding frequencies are shown in Table 110.

Table 110. Check-in Interview 6 Coding Frequencies – CB1

Code	**Abbreviation**	**Frequency of Responses ($N = 36$)**	**Percentage of Total Responses (%)**
Attitudes	A-c	4	11.1
Knowledge	K-p	1	2.8
	K-c	1	2.8
Skill	S-c	1	2.8
Goals	G	2	5.6
Experience	E	7	19.4
Feedback	F	5	13.9
Teaching	T	3	8.3
Interaction	I	4	11.1
Reflection	R	8	22.2

Attitudes (A-c)

In terms of attitudes, Taylor reflected on the relevance of a professional development session they attended earlier that same day, which focused on teacher burnout. They shared their feelings of burnout due to family circumstances, new high school teaching standards, and the workload of their Fall 2022 semester in the MS program. After reflecting on a difficult semester, they shared feeling like they were "in a much better state of mind."

- "We have an 8-week-old baby now, so that's the second baby, so that adds a certain level of chaos. I think I'm a little burnt out to be honest. It's funny because I actually went to a [professional development] session today on teacher burnout, and this isn't a reflection of the program, or my high school. I think it's more a reflection of me and my personality and all of things in life coming together at once, where I just happened to start the master's program at a point in time in which my family was just starting and we happen to simultaneously be integrating new standards [that] were released for teaching high school. [The] collective demand that everything placed, especially in the fall, when I have two pretty high demand content courses in SDSU, I can just get knee deep into my work, and then that creates kind of this self-fulfilling prophecy of I go to bed way too late, and then that leads to not getting enough sleep which leads to avoiding this and avoiding that and doing this, and so I'm in a much better state of mind right now and I got some good resources on that."

Taylor continued their reflection on "teacher burnout," including their recent feelings of resentment and cynicism. Overcoming these mental obstacles during their tenth year of teaching allowed them to be "in a better place" in terms of their teaching motivation.

- "I definitely related to it where it was like resentment toward work and general cynicism and things like that. I've never felt this way about my kids – not my biological kids, but like my students – and just going to work in general. As my tenth year teaching, I've just never had these levels of cynicism about certain things before, and I do think part of it is it's so hard to evaluate how much of that is at least in part a product of the pandemic and the students are different now than they were 3 years ago, so it's just so hard how much of it is me versus how much of it is the changes that they've gone through versus the expectations that are placed on me. So yeah, I'm doing much better now, though. So that's good. I'm in a better place for that."

Taylor discussed the emotional toll of changing their action research plan. The logistical component of the project necessitated a delay in their data collection, so Taylor was forced to change their research topic. They shared their thought process behind shifting from stoichiometry to molecular bonding, identifying the impact this setback had on their attitudes.

- "I still need to do the IRB stuff, but I felt I was at a really low point after this because I was so excited to do the stoic stuff, so I really was interested in that. I'm also interested in molecular bonding stuff, but I had just kind of created the conditions in which I missed my point with the stoic stuff unless I did it next year. I just didn't see a way around that, and I didn't want to wait another year."

Relating to an inventory they plan to use in their action research project, they expressed feelings of excitement.

- "I'm super excited to get that inventory. I like inventories way more than I probably should."

<u>Summary of Attitudes (A-c)</u>

Taylor expressed various attitudes toward their profession, MS course requirements, and action research project during their second year in the MS program. They described experiencing "teacher burnout," including "resentment toward work and general cynicism." They attributed some of these attitudes to changes in their students and teaching since the COVID-19 pandemic, as well as the demands of the MS program and their family life. They described being in “a better place” as of the beginning of Semester 4. After describing the mental toll of changing their action research plan, they expressed positivity toward finding a resource to use as a data collection method.

Knowledge (K-c) and Skill (S-c)

Due to the KoSc they gained through MS program courses, Taylor discussed improvements to their pedagogical skill. By combining their KoSc and KoT, Taylor demonstrated improvements to their PCK quality. They specifically described having a better ability to explain content. Relating to the “Teaching” code, Taylor also shared improvements to their KoCO as a component of their PCK by making choices to teach new content.

- “I feel like it has something to do with making changes to the content which I'm teaching. I know more about chemistry stuff, so I either have come up with sort of a better way to express and relay information related to whatever the said topic is, whether that's via talking or via visuals or via a resource.”

Goals (G)

Taylor described two main goals for the remainder of their time in the MS program. The first goal was to complete the final content course for their MS degree.

- “So obviously finishing out the content aspect. As far as I know, I'm in my last content class.”

The second goal related to their research, in terms of preparing, executing, and defending their action research project.

- "Getting the logistical piece of the research down in pinning the research question down. because again it's one of those things that it's like I know what I want to do, but it's still relatively recent since I've detached from the stoichiometry idea and finalized that decision in my mind where it's like 'God, I spent months researching and thinking about that' where I need to get clarity. Gaining clarity in my research, taking care of the logistical pieces, actually gathering the data. And then following through in the summer with defending it and putting it together. Preparing for the defense."

<u>Experience (E)</u>

During the sixth check-in interview, Taylor shared experiences that took place during their time in the MS program. They first discussed courses they are taking during Semester 4. They described the familiarity of taking a class from Instructor A due to past experiences.

- CHEM 773 "is my fourth class with Instructor A, so I feel very familiar with when things are due, the format, when to expect certain things, [and] how to seek help. There's a familiarity piece built into that which makes it better."

They shared that they are registered for two courses – CHEM 788 and CHEM 773 – relating to research and chemistry content. They also described their level of prior knowledge (K-p) related to equilibrium and acid-base chemistry, demonstrating their baseline KoSc for these topics.

- "I feel much better. I know I'm registered for more than one class, because it's technically 788 is happening, but it's not like an active class that I'm actively completing homework for and quizzes and stuff like that. And equilibrium and acid-base chemistry is relatable enough to me that I'm not from scratch on it."

Taylor expressed positive attitudes (A-c) toward continuing their action research project after changing topics. They described their experience choosing a new topic relating to bonding and finding a resource to use in their data collection (KoR). By gaining KoR, Taylor increased their overall PCK.

- "There's reason for optimism. We're going to be getting into our bonding unit later down the road and I feel a lot better now because I was doing my literature review for it and trying to focus on misconceptions related to bonding. I happened to come across in J. Chem Ed a development of a bonding representations inventory which is an inventory for categorizing misconceptions related to molecular bonding and not only that, but how those misconceptions come into play using various representations like a Lewis structure. Anyway, the professor at Miami of Ohio granted me access to that. Now I have that and to me that felt like, 'oh, my God! Now I can begin'."

Later in the interview, Taylor described their experience with the teacher-initiated study groups in Semester 4.

- "This is the first time somebody else actively took the reins and threw the email out there [to organize the study group]. In the past in the classes that I've been in, I've initiated it. I don't personally care. It doesn't need to be me, doesn't matter who it is. I did not go to last night, but it's something that again now, with two kids in the bedtime, and it's a Sunday at 8 so it's easier said than done sometimes."

Taylor discussed their ability to watch a recording of the study group Zoom session if they had been unable to attend. Even if they could not attend the study session synchronously, these interactions still have the potential to aid Taylor's development of PCK.

- "But yeah, I still intend to make it as much as I can, and they're recorded. That's nice, too. Somebody records it and then posts it later on. It's nice to be able to watch at a later date if needed if I can't make the live one."

Summary of Experience

Taylor shared experiences from the MS program and their teaching in Semesters 3 and 4. They described feeling familiar with Instructor A's courses, which allowed them to feel better about their workload during Semester 4, especially considering recent changes to their family life. They discussed their experience preparing for their action research project after switching topics. In terms of interacting with other MS program participants, Taylor talked about the organization of the study groups and the difficulty to fit those meetings into their schedule during Semester 4. Recordings of the study group sessions made it possible for teachers to participate asynchronously.

Feedback (F)

Taylor shared five comments coded as feedback. These statements were further analyzed using Codebook 3, which will be shared in the section below.

Teaching (T)

Taylor described how the MS program has impacted their teaching. They were inspired to bring literature into their chemistry classes based on texts from Instructor A's courses. This demonstrates their KoG related to integrated understanding, which reveals an improvement to their PCK.

- "I think that's great to incorporate literature in a way that I wouldn't have thought about doing in the past, and so I've actually found ways to try and incorporate those books into my own high school chemistry setting, or even if it's just telling stories from those books, but we've talked several times in our study groups about some of these fascinating radiation stories [from *Strange Glow*], and how we could infuse that into our nuclear unit at a high school level just to capture attention."[74]

Taylor also discussed using a resource from CHEM 774 in their teaching, demonstrating an impact of an MS program course and an improvement to their KoR as a component of their PCK.

- "I might have used this particular resource in the past, but we used this really great reduction potential table [in CHEM 774] and I actually gave that table to my Honors students and that's what they used to evaluate their redox reactions last quarter."

They also reflected on the pedagogical impacts of the CHEM 778 course focusing on chemistry teaching strategies. This course impacted Taylor's PCK in terms of their KoT and KoG. By combining these knowledge bases, Taylor experienced improvement to their PCK quality. They elaborated that the MS program has reaffirmed their philosophy of science education.

- "Pedagogically, it still comes back to the [CHEM 778] course that I took last spring that's poking its head in various ways where we're focusing on more data to concept stuff rather than just concepts data that general approach. I wouldn't say that's a sole result of having taken the classes, but it's amplified some of the notions that I had about higher quality science instruction. It reaffirmed that for me."

Summary of Teaching

Taylor's experience in the MS program impacted their teaching by exposing them to new chemistry content, resources, and pedagogical techniques. Through their application of new knowledge, skills, and resources, Taylor demonstrated improvements to their KoG, KoT, and KoR, which contributed to the overall improvement of their PCK.

Interaction (I)

Taylor described their experience interacting with other teachers in the MS program through study groups during the CHEM 774 course in Semester 3.

- "We had good relationships, good study group meetings with Instructor A's class where we would meet on our own, and that was that was all well and good, so good impressions."

They elaborated on the study group sessions, which focused mainly on chemistry content and homework assignments; however, MS program participants occasionally discussed common teaching challenges. These conversations allowed teachers to exchange KoSt, KoT, and KoR, which allowed them to further improve their PCK in community with one another.

- "Yeah, I'd say 90% of the conversation is content-specific where we're actively going through our homework, but toward the end of most meetings somebody initiates some struggle [they're] going through and it's a collective session, so to speak, for teachers. Sometimes it's [about] pedagogy. Sometimes it's [about] ideas. Sometimes it's just: 'do you guys see similar misconceptions?'"

Reflection (R)

Taylor reflected further on the professional development session at their school when discussing the issues they faced when completing the logistical aspects of their action research project.

- "In December [2022], I had a clear idea of what I wanted to do, and then just never followed through with the logistical IRB aspect stuff. I was constantly 'Oh, My God, I haven't submitted this yet, but I will.' And then it reminded me what I went through this in this [professional development] session [on teacher burnout] is you find ways to avoid something that is causing you more stress and so you just avoid it, and I know what I want to do, just let me do it sort of thing, and I know after taking the [CHEM 788] I know I shouldn't just do that without getting like approval for the IRB. I was like 'if I'm going to do this, I want to do it right.'"

They reflected on their need to consult their research advisor for guidance on their action research paper, including submitting their IRB application.

- "I'm meeting with Instructor B on Friday, so that'll give me a good clear idea of how to proceed in a very efficient way to be like, "okay, how do I-" Because I can write a 15 page paper in a day or in a weekend and not say it's perfect, but to do a well enough literature view, all that stuff. It's more the administrative stuff like the IRB stuff. How do I do this well, how do I get this done quickly? What do they need to see? You know that sort of stuff. So that's I feel a little bit better about it."

When discussing their experience in Semester 3, Taylor shared their success in both MS content courses.

- "I made it through both [Fall 2022 content courses] just fine. I got an A in both, so it's like 'yay.'"

As discussed in their previous check-in interview, Taylor brought up their department's choice to read *Ambitious Science Teaching*, emphasizing the impact these discussions may have on their department's teaching approach.[72]

- "All of a sudden, department members at my school, completely independent of me said, 'hey, let's start a book club. And, by the way, we're going to read the book *Ambitious Science Teaching'* and it's like 'Oh, my God! That was my textbook for this class and we basically had a book club on that via our class.'[72] Now it's going to be awesome to take the ideas that we talked about in [CHEM 778] and communicate those ideas with not just any teachers now, it's the people that I actually work with, so now they stand at a greater chance of being integrated into school."

Taylor reflected favorably on their course load for Semester 4.

- "I'm not really worried about the content class in the sense of concern. It'll get the appropriate attention it needs, but this is nice, having this one class, because it'll allow me to delegate more time to the research aspect that I need to."

<u>Summary of Reflection</u>

Taylor reflected on the cause of their recent professional burnout and described how it has manifested itself in regard to their action research project. They hoped to gain clarity about next steps for their research project upon meeting with their advisor. They felt successful in the Semester 3 content courses and felt confident about their workload for Semester 4, in terms of coursework and research. They again brought up their department's book club over *Ambitious Science Teaching*, stating its potential impact on their departments' collective teaching approach.[72]

Codebook 3

Taylor shared five comments coded as "Feedback." These statements were further analyzed using Codebook 3. These coding frequencies are shown in Table 111 below.

Table 111. Check-in Interview 6 Coding Frequencies – CB3

Code	**Abbreviation**	**Frequency of Responses (*N* = 5)**	**Percentage of Total Responses (%)**
Course Feedback	CF	1	20
Program Feedback	PF	1	20
Course Delivery Feedback	CDF	1	20
Logistical Feedback	LF	2	40

Course Feedback

Taylor appreciated the incorporation of books into Instructor A's courses.

- "This was specific to Instructor A, but I liked the book *Strange Glow* that we read.[74] I like that book. This doesn't need to be true for every course. For example, they've yet to find a book that ties nicely into equilibrium, which is not too surprising, but they've found a great book on radiation. They've found a great book on atomic theory."

Program Feedback

Taylor detailed the support they received from their research advisor throughout the process of developing and executing their action research project.

- "One thing that I've always appreciated with Instructor B, who's been helping me out throughout this process, is their availability and willingness to contribute ideas and talk through ideas and just be honest about 'You know this is a good idea, this is not a good idea, or maybe we should think about this instead of that' and providing clarity on things."

Course Delivery Feedback

Taylor shared feedback regarding the course delivery of CHEM 775, voicing their desire for video lectures from their specific instructor.

- "In [CHEM 775], it was just a different philosophical teaching modality. A lot of it felt outsourced or a lot of it was Chem LibreText. It would just be nice to have 'this is my professor, and this is my professor giving a lecture on organic naming or structures, or reactions' and because it wasn't that, a lot of it was very self-learning. There were more resources this time around like Khan Academy videos, which is nice."

Logistical Feedback

Taylor appreciated online software that provided immediate feedback so learning could actively take place while they completed homework problems.

- “I really like that software that provides formative feedback and so learning was often being done actively in that moment while I was doing homework as opposed to applying previously learned ideas to practice set ideas.”

Taylor hoped for more uniformity across MS program courses, especially in terms of communication. They discussed the value of having a weekly email with weekly reminders for each course.

- “It'd be nice to have a little bit more uniformity across classes. I thought the communication has been good. It's a hybrid setting. Communication is so key and doing that well, not just from a communication point of view, but also what is the platform upon which we communicate? One thing I will say that I was talking about this with someone else in the program is it's really nice every week that Instructor A, for example, will send out an email that's ‘here are the assignments for the week.’ Even though technically those are on the syllabus and I could technically look that up it's nice to just have a ‘oh, yeah, things are due, and things to remember for the future.’ Every beginning of the week email to put you in that modality of like ‘oh, yeah, this is due this week,’ would be something that's nice. I don't honestly remember if Instructor B did that. They may have. I just don't remember. It's required for us to post weekly learning guides at the high school level, especially during the pandemic, when they were all virtual. In a virtual setting, communication is key, and so if there can be a standard set to be like, teachers would really appreciate having something at the beginning of the week where it's like, ‘hey, I know you have access to this stuff, but just an FYI, here's what's due for this week,' because I've talked to several people who have liked that, and I am in agreement with them."

Codebook 4

Codebook 4 was used to demonstrate the motivations behind Taylor's comments. These coding frequencies are shown in Table 112 below.

Table 112. Check-in Interview 6 Coding Frequencies – CB4

Code	**Abbreviation**	**Frequency of Responses (*N* = 19)**	**Percentage of Total Responses (%)**
Learning-focused	L-f	11	57.9
Teaching-focused	T-f	8	42.1

Most of Taylor's comments related to their own learning that took place during the MS program (57.9%), while many of their thoughts were motivated by their teaching (42.1%). They did not share any statements related to implications for student learning. An example of each coded responses is given below.

- "Equilibrium and acid-base chemistry is relatable enough to me that I'm not from scratch on it" in the CHEM 773 course. (L-f)
- "I've actually found ways to try and incorporate those books [from CHEM 770 and CHEM 774] into my own high school chemistry setting, even if it's just telling stories from those books." (T-f)

Summary of Check-in Interview 6

Taylor discussed their experience in their third semester of the MS program and shared their goals for Semester 4. Most of Taylor's comments related to what they learned in the MS program (57.9%). The remainder of their statements were motivated by their teaching (42.1%). The main themes from Check-in Interview 6 were:

- Taylor reflected on a professional development session on teacher burnout they attended prior to the interview. They reflected on their own recent burnout due to the demands of the MS program, their teaching, and their family life. They described being in "a better place" at the start of Semester 4 due to the more manageable workload and support via teacher-initiated study groups.
- Taylor applied new content knowledge to their teaching, which had a positive impact on their pedagogical skill. They improved their ability to explain chemistry topics through their KoSc, KoCO, KoT, and KoR. These positive changes demonstrated increases to the quality of their PCK.
- Their remaining goals for the program were to complete their content course requirements and prepare, execute, and defend their action research project.
- Taylor shared positive feedback about the incorporation of books into the content courses, the support of their research advisor, and the use of an online homework software. They hoped for more video lectures from their specific professor and more uniformity across courses, especially regarding weekly communications.

CoRe

In Spring 2023, the CoRe was administered in CHEM 773: Equilibria & Acid-Base Chemistry. The CoRe was analyzed using Codebook 2 to assess participants' PCK.

Table 113 displays the codes from Codebook 2 that appeared in Taylor's Semester 4 CoRe.

Table 113. CoRe Coding Frequencies for Semester 4 – CB2

Code	Abbreviation	Frequency of Responses (N = 33)	Percentage of Total Responses (%)
Knowledge of science	KoSc	5	15.2
Knowledge of goals	KoG	3	9.1
KoSt	KoSt	6	18.2
Knowledge of curriculum organization	KoCO	2	6.1
Knowledge of teaching	KoT	8	24.2
Knowledge of assessment	KoA	6	18.2
Knowledge of resources	KoR	3	9.1

KoSc

The first component of PCK represented in the CoRe is KoSc, which includes science content, scientific practice, the nature of science, and scientific progress.[41] Taylor chose to focus their CoRe lesson on weak acid-base titrations and explained the reasoning behind their topic choice below.

- "I chose this topic because it wasn't until recently that I felt reasonably confident in my conceptual and mathematical understanding of what is taking place throughout this type of titration."

Taylor listed the following as their intentions for student learning, connecting to their KoCO. This combination of knowledge bases demonstrates improvements to the quality of Taylor's PCK.

- "Calculate the pH of a weak acid/base titration at various stages of the titration (initial, ½ equivalence point, equivalence point). Write neutralization reactions. Recognize and explain how the formation of certain salts affect the pH of the solution at the equivalence point. Graphically represent and interpret the progress of a titration. Model the progress of a titration with particle diagrams."

They then expanded on the additional knowledge they had related to buffer solutions and acid-base titrations, comparing their content knowledge to their expectations for students (KoSt). By combining their KoSc and KoSt, Taylor demonstrated improvements to their PCK quality.

- "The formation of a buffer solution prior to the equivalence point often plays a significant role in this titration type. Though I do expect students to utilize the Henderson-Hasselbalch equation to determine pH, I don't expect students to have a deep understanding of buffers beyond their basic function and knowing when a buffer solution has formed."

- "Not all weak acid-strong base titrations result in the formation of a buffer solution. If the acid:base concentration is beyond 10:1 or beyond +/- pKa of 1, it may be more appropriate to take a different mathematical approach to finding pH. However, all weak acid/base titrations they do will form a buffer and we will assume that it's still OK to apply the H-H equation."

Summary of KoSc

In their presentation of their CoRe lesson, Taylor demonstrated their knowledge of weak acid-base titrations, buffers, and other CHEM 773 topics. The main themes for KoSc were:

- Due to their improved confidence in their content understanding, they chose to create a CoRe for weak-acid base titrations. Taylor also provided details of their additional knowledge of CHEM 773 topics beyond what they would teach. This demonstrates improvements to their KoSc as a component of their PCK.
- Taylor was able to list intentions for student learning, connecting to their KoCO and KoSt. This combination of knowledge bases demonstrated improvements to their PCK quality.

KoG

The next code for the CoRe assignment relates to KoG, which may include learning goals for scientific literacy, real-life application, and integrated understanding.[41] Taylor described the importance of learning their chosen topic, which related to making connections between chemistry topics and discussing the relevance of weak acids and bases in everyday life.

- "I think weak acid/base titrations provide a wonderful and challenging opportunity for students to connect multiple concepts in chemistry. Such concepts included molarity, stoichiometry, equilibrium, acid/base properties of salts, pH, buffers, and neutralization. If properly understood, this potluck of concepts ties together in a cohesive manner that requires a firm grasp of these underlying ideas. Though challenging, I think it can be very useful to see how such concepts are actually applied in novel ways that go beyond the narrow focus of when they may have originally learned each concept."
- "I also think it's important simply because it's rare for all acid-base reactions to involve a strong acid and strong base. For example, if we ever wanted to determine the concentration of acid in something we consume, like vinegar, we're going to need to understand how the presence of a weak acid impacts the titration."

Summary of KoG

Taylor revealed their KoG by discussing their intentions behind teaching weak acid-base titrations. They discussed the value of students being able to make connections to previously learned content, as well as the relevance of weak acids and bases in their students' lives. By combining their KoG and KoSt, Taylor demonstrated improvements to their PCK quality.

KoSt

The next code is KoSt, which may focus on different learning levels, needs, interests, prior knowledge, ability, learning difficulties, and misconceptions.[41] Taylor chose to teach their CoRe lesson to their Honors Chemistry class. They expressed their knowledge about students' thinking by discussing the need for scaffolding to support student understanding and common points of confusion. By combining their KoSt and KoT, Taylor demonstrated improved PCK quality.

- "As novice chemistry learners, students often have difficulty with forming relationships between ideas and navigating multiple levels of understanding. Therefore, a certain degree of structure is needed if we are to tackle such titrations."
- "Because of the complexity, students may easily confuse the application of one idea with another along various points of the titration."

KoCO

The next code relates to KoCO, which may relate to state and local standards.[41] Taylor provided a relevant state standard related to acid-base reactions. Throughout the CoRe, Taylor made decisions about what to teach based on their KoSc, KoSt, and KoCO. This combination of knowledge bases revealed improvements to the quality of Taylor's overall PCK.

KoT

The next code is KoT, which involves the discussion of teaching methods and activities.[41] First, Taylor shared their ability to alter their teaching approach through their creation of a CoRe.

- "I think back to how I've taught this in the past and I feel like it was very narrowly focused, too algorithmic and there was too much communication at the symbolic level (math and chemical equations, graphs, etc.). With my improved understanding, I want to see how I approach teaching this concept differently than in the past and what I can do to include more levels of chemical understanding that go beyond just the symbolic level."

They then discussed difficulties or limitations associated with their teaching of weak acid-base titrations. They first discussed the importance of providing students with strong foundational understanding of acid-base chemistry before they teach titrations. By combining their KoSt and KoT, Taylor demonstrated improvements to their PCK quality.

- "I think the primary feature with teaching this concept that makes it difficult is ensuring the underlying concepts are understood as they are being applied throughout the titration. For example, at some point I might say something like, 'we can see that now we have X mol of acid and X mol of conjugate base present, so that means we are dealing with a buffer solution.' That sentence alone presumes the learner not only understands what a buffer solution is but what effect it will have on our approach to determining pH at that point. This same kind of issue appears when discussing the equivalence point and even the initial pH of the weak acid solution. Therefore, it's essential that we continuously reflect on our understanding of what these underlying concepts mean so that when we apply them, we aren't simply doing it in a purely algorithmic manner that is absent of meaningful understanding."

Modeling was an important component of Taylor's instruction of acid-base titrations.

- "To help with [student difficulties], I would not solely teach this concept at the symbolic level with equations and graphs. In addition to those things, I would have students model what they think is present at the particle level throughout the titrations. Since this modeling of particles isn't meant to be quantitative, it may be easier to connect what's taking place in the solution with how we symbolically represent that situation."

They further discussed a scaffold they would use to support student learning of weak acid-base titrations. By combining their KoSt, KoG, and KoT, Taylor demonstrated improvements to their PCK quality.

- "I would want to work with [students] to build a generalized graph for a weak acid/base titration that communicates at what stages certain equations/approaches are used to determine pH. This scaffold can be quickly referenced in the future and will allow them to more easily chunk certain information so their focus can be applied to other important things they are trying to communicate about the titration."

Taylor then shared three teaching procedures for their CoRe lesson. Their first step would be to allow students to create models, thus allowing them to participate in the learning process and allowing them to visualize the titration process. By combining their KoG, KoSt, and KoT, Taylor demonstrated improved PCK quality.

- "Student-generated models of various stages through the titration process using colored magnets, bingo chips, or drawings. As previously mentioned, I want to ensure I'm incorporating multiple levels of understanding when teaching this. Though we will certainly utilize symbolic understanding, it should not be the sole focus. Engaging in multiple levels will increase the likeliness that students are making the necessary connections to the equations and graphs that we will inevitably use."

They again placed students at the center of their learning by providing them with questions to make the problem-solving process more accessible.

- “To help avoid an overreliance on algorithmic thinking when attempting to determine the pH at various stages, think about helping them develop a set of ‘approach questions' they need to ask themselves that can be consistently applied. These approach questions may help break down a problem into its components and make conceptual problems more attainable for some students.”

Taylor then shared their plan to perform a demonstration that would prompt discussion and expose misconceptions (KoA). By combining their KoT and KoA, they demonstrated higher quality PCK. They also connected to their goal to have students think more deeply and make better connections between chemistry concepts. By combining their KoG and KoT, Taylor revealed improved PCK quality.

- “Provide a demo where the outcome doesn’t necessarily align with expectations. Asking students to explain anomalies can make it clear where a misconception is and to what extent. This can help expose overreliance on algorithmic thinking or a lack of connection between concepts.”

When describing the factors that influence their teaching of this topic, they discussed the math associated with titration calculations.

- “The variety of math that’s involved when we are trying to calculate pH at various stages is something that will need to be practiced and checked on numerous times. Whenever math is involved, especially when being applied to a difficult concept, it's easy to overlook subtle details or to not take into consideration relevant factors. Therefore, I need to ensure students are given adequate exposure to a variety of problems while mixing up what is being emphasized in those problems."

Summary of KoT

Taylor outlined their teaching approach for their CoRe lesson. The main themes for teaching were:

- Taylor used the CoRe module as an opportunity to improve their teaching after increasing their KoSc through the CHEM 773 course.
- Taylor shared multiple teaching procedures focused on student-centered learning. Their approach allowed students to apply concepts and move away from "algorithmic thinking," connecting to their KoG.
- Taylor incorporated modeling and scaffolding techniques into their instruction to provide a more meaningful learning experience for students.
- Taylor was aware of difficulties associated with weak acid-base titrations, including mathematical processes, which influenced their teaching approach for their CoRe lesson. They again demonstrated their KoSt and KoT by exposing potential misconceptions and making changes to support student learning.

KoA

The next code is KoA, which details teachers' knowledge of formal and informal assessments and feedback.[41] Taylor integrated assessments into their CoRe teaching procedures. They discussed their use of frequent assessments to expose misconceptions and encourage deeper understanding.

- "Due to the reliance on prerequisite skills and variety of concepts within this topic, it's essential that I provide frequent (low-stakes) assessments throughout to catch misconceptions early on before they become a problem down the road."
- "When providing opportunities for assessment, don't silo myself into using only pencil-and-paper assessments. Think about how to incorporate more authentic assessments that bring out conceptual understanding. Attaching experiences to concepts may help deepen the ways students think about the properties they observe."

Taylor then discussed additional methods for assessing student understanding or confusion. They placed students at the center of their learning, allowing them to make predictions based on their prior knowledge.

- "Using NaOH for the base, titrate HCl and acetic acid that both show the same initial pH. Many students will initially expect that both acids will require the same amount of base is needed to reach the equivalence point. This will present an opportunity for them to try and make sense of why one acid required more base than another and will emphasize the role that acid-base strength plays in titrating a sample."

Similarly, Taylor demonstrated their KoSt by identifying potential misconceptions related to the equivalence point. This combination of their KoSt, KoSc, and KoA revealed improvements to the quality of Taylor's PCK.

- "Asking [students] to explain why the pH is greater than 7 at the equivalence point when titrating a weak acid with a strong base. Since they know all of the original base is consumed at pH of 7, many will have difficulty with attempting to come up with an explanation for where the additional OH^- is coming from. This will expose misconceptions related to the role of properties of certain salts."

By involving a real-world connection in their lab activity, students could apply their knowledge and skills to a common household product (KoG). This combination of their KoG and KoA revealed improved PCK quality.

- "Asking students to perform a kind of 'quality control' test by determining whether the vinegar bought from the store is actually 5% acetic acid like it says on the label. This will involve the application of a variety of skills and will therefore create multiple opportunities for students to identify areas of weakness in their understanding if they aren't able to perform this task properly."

Summary of KoA

Taylor integrated assessment into their CoRe lesson in order to expose student misconceptions and check students' understanding. The main themes for KoA were:

- By including assessment methods in their teaching procedures, Taylor demonstrated the value of assessing student learning during instruction. This combined their KoA and KoT, revealing PCK.
- Many of Taylor's methods for assessing student confusion placed students at the center of their learning. These opportunities allowed for students to apply their knowledge while Taylor observed whether any misconceptions were present. By combining their KoSc, KoG, KoSt, and KoA, Taylor demonstrated improvements to their PCK quality.

KoR

The final code in Codebook 2 relates to KoR, which discusses materials and activities that teachers utilize in their classrooms.[41] Taylor demonstrated their awareness of laboratory materials used in titrations, as well as their knowledge of a demonstration and materials to use when students are developing models.

Summary of CoRe Data

Taylor demonstrated their knowledge of CHEM 773 topics through their CoRe lesson. The main themes from their Semester 4 CoRe were:

- Taylor combined their KoSc, KoG, KoA, KoSt, and KoT by creating relevant classroom activities that allowed for student-centered learning and assessment, which demonstrated improved PCK quality.
- They were able to detail their chemistry content knowledge of weak acid-base titrations and adapt their knowledge to an Honors Chemistry course level. Their application of their KoSc to a teaching situation (KoT) indicated higher quality PCK.
- Taylor outlined their teaching procedures for their CoRe lesson, involving modeling and scaffolding techniques (KoT), which revealed improved PCK.

Module Survey – CoRe

After completing the CoRe assignment, Taylor was invited to complete a survey about their experience creating a CoRe for their topic. The CoRe module survey was coded using Codebooks 1 and 4. Taylor did not provide any feedback in the CoRe module survey, so Codebook 3 was not used.

Codebook 1

Coding frequencies for Codebook 1 can be found in Table 114.

Table 114. Module Survey Coding Frequencies for Semester 4 CoRe – CB1

Code	**Abbreviation**	**Frequency of Responses (*N* = 11)**	**Percentage of Total Responses (%)**
Attitudes	A-c	2	18.2
Knowledge	K-c	1	9.1
Skill	S-c	2	18.2
Teaching	T	2	18.2
Reflection	R	4	36.4

Attitudes (A-c)

Taylor shared their feelings about teaching their CoRe lesson without preparation.

- “I could do [teach without preparing beforehand] reasonably well, but I wouldn't feel good about it.”

When asked about their confidence level on a scale of 1 to 6 for teaching their concept, Taylor responded with a score of 5.

Knowledge (K-c)

Taylor described the impact of the CHEM 773 course on their content understanding.

- The CHEM 773 course content “has helped me understand what's taking place throughout the entirety of the titration, rather than just the equivalence point or the initial point.”

By improving their KoSc, the CHEM 773 course enabled Taylor to enhance their PCK.

Skill (S-c)

Taylor discussed their current skill level of using modeling techniques in their instruction of weak acid-base titrations.

- “I don't have a lot of experience modeling weak acid/base titrations at the particle level.”

They also described an increase to their pedagogical skill due to improved content knowledge (KoSc).

- “As a result [of gaining knowledge in the CHEM 773 course], I felt like I could more easily help students represent the entire titration process rather than bits and pieces.”

These statements combined their KoT and KoSc, which revealed improvements to the quality of Taylor’s PCK.

Teaching (T)

Taylor shared the reasoning behind their desire to prepare before teaching their CoRe lesson. They demonstrated their KoT and KoCO by identifying instructional plans they would like to have in place in order to best support student learning. This combination of knowledge bases indicated improved PCK quality. They also demonstrated their teaching philosophy by making teaching choices that benefit their students. By integrating their KoG and KoSt into their KoT, Taylor demonstrated higher quality PCK.

- “This particular topic requires the appropriate structures to be in place so that ideas can be more easily connected in the minds of students. If I wasn't prepared, those structures wouldn't be adequate, and I think it would negatively impact their learning.”
- “Additionally, I would want to have certain questions planned ahead of time that would allow me to make certain instructional decisions along the way.”

<u>Reflection (R)</u>

Taylor discussed the amount of reflection required to make a CoRe, particularly related to stating the reasoning behind their teaching choices. This reflection allowed for PCK and professional development.

- “I didn't find it overly challenging [to create a CoRe]. I suppose the most challenging part is just the fact that you needed to step back and clearly reflect on what exactly you're trying to do and why. Explaining the rationale behind what I was doing at various points was probably the most challenging part.”

Taylor also reflected that gaining experience would improve their teaching confidence.

- “I think having this experience [teaching the CoRe lesson] would make me feel a bit more confident.”

Taylor reflected on how the CoRe allowed them to reconsider how to teach weak acid-base titrations. The module allowed Taylor to reflect on their teaching practice, which enhanced their KoT, KoA, and KoCO and, thus, the overall quality of their PCK.

- The CoRe “has allowed me the opportunity to think about how I would check for understanding while teaching this concept in ways that I hadn't previously considered.”

- “Additionally, [the CoRe] has helped me realize the emphasis I need to place on multiple levels of understanding when teaching chemical ideas.”

Codebook 4

Codebook 4 was used to identify the source of motivation that fueled Taylor’s comments. Coding frequencies can be found in Table 115.

Table 115. Module Survey Coding Frequencies for Semester 4 CoRe – CB4

Code	**Abbreviation**	**Frequency of Responses (*N* = 9)**	**Percentage of Total Responses (%)**
Learning-focused	L-f	1	11.1
Student-focused	S-f	2	22.2
Teaching-focused	T-f	6	66.7

Taylor shared statements primarily motivated by their own teaching (66.7%), but also included statements focused on student-focused (22.2%) and learning-focused (11.1%) motivations. An example of each code is given below.

- The CoRe “has allowed me the opportunity to think about how I would check for understanding while teaching this concept in ways that I hadn't previously considered.” (T-f)
- “This particular topic requires the appropriate structures to be in place so that ideas can be more easily connected in the minds of students.” (S-f)

- The CHEM 773 course content “helped me understand what's taking place throughout the entirety of the titration, rather than just the equivalence point or the initial point.” (L-f)

Summary of Module Survey – CoRe

Taylor used the CoRe module survey to reflect on how the CHEM 773 course content has impacted their teaching of weak acid-base titrations. Their responses mainly included teaching-focused motivations (66.7%); however, they also shared comments related to their students’ learning (22.2%) and their own learning (11.1%). The main themes from this survey were:

- Taylor used the CoRe assignment to reflect on their teaching choices and consider changes they would make to their lesson to further benefit student learning. This combination of their KoT, KoA, KoSt, and KoCO led to enhancement of their PCK quality.
- The CHEM 773 course improved Taylor’s chemistry content knowledge, which positively impacted their pedagogical skill, showing improved PCK quality through the combination of their KoSc and KoT.
- Taylor felt confident in their ability to teach their chosen concept but did not feel comfortable doing so without preparation. Their responses reflected their desire to have “structures…in place” that would support student learning, connecting their KoG and KoT and demonstrating improved PCK quality.

Teaching Observation 4

Taylor’s fourth teaching observation was over the same topic that they chose in Semester 2. Because of this, some of their answers to the pre-observation survey are identical. This indicates a lack of change in their KoSt and KoG for their teaching of electron configuration and the quantum atomic model. Additions to their surveys will be highlighted in order to focus on potential changes in their PCK from Semester 2 to Semester 4.

Pre-Observation Survey

Upon scheduling the Zoom teaching observation, I sent the pre-observation survey to Taylor by email to complete prior to the observation. The pre-observation survey was coded using Codebooks 1, 2, and 4.

Codebook 1

Codebook 1 coding frequencies are shown in Table 116.

Table 116. Pre-Observation Survey Coding Frequencies for Observation 4 – CB1

Code	**Abbreviation**	**Frequency of Responses (*N* = 9)**	**Percentage of Total Responses (%)**
Attitudes	A-c	3	33.3
Knowledge	K-c	1	11.1
Skill	S-c	1	11.1
Teaching	T	4	44.4

Attitudes (A-c)

Taylor shared positive attitudes toward teaching this lesson.

- “I feel good about it. I like talking with the kids about the weirdness of the quantum world and teaching electron configuration.”

Taylor indicated that they felt confident teaching this lesson. They also felt confident in their students’ ability to learn this topic (KoSt), which demonstrated their PCK.

- “When it comes to electron configuration, they will do just fine. I have no concerns about this.”

<u>Knowledge (K-c) and Skill (S-c)</u>

As a result of gaining content knowledge (KoSc) in the MS program, Taylor expressed improvements to their teaching confidence and pedagogical skill. By combining their KoSc and KoT, Taylor demonstrated higher quality PCK due to the CHEM 770 course.

- “CHEM 770 – Atomic Theory helped me out a great deal. Since I feel like I understand it so much better, I can explain it better and make a variety of different connections in ways that I may not have been able to previously.”

<u>Teaching (T)</u>

Taylor shared comments related to their KoT. Taylor chose to teach their lesson on electron configuration and the quantum atomic model, the same topic they used for their second teaching observation. They described the layout of the lesson, including how it fits into their curriculum. By combining their KoCO and KoT, Taylor displayed higher quality PCK.

- “It’s a bit more direct instruction than I like to do but we recently did an inquiry-based activity and certain gaps in understanding need to be filled in.”

They shared their desire to incorporate more assessment into their lesson to check for student understanding, demonstrating their KoA as a component of their PCK.

- "More built-in time for checking their understanding to ensure that they are understanding the things I'm intending instead of just assuming they get it."

As stated in their second pre-observation survey, they hoped this lesson would prompt interesting discussion in their class.

- "Hopefully, it may spark some interesting questions, but we'll see."

Codebook 2

Codebook 2 coding frequencies can be found in Table 117.

Table 117. Pre-Observation Survey Coding Frequencies for Observation 4 – CB2

Code	**Abbreviation**	**Frequency of Responses (*N* = 9)**	**Percentage of Total Responses (%)**
Knowledge of science	KoSc	1	11.1
Knowledge of goals	KoG	1	11.1
Knowledge of students	KoSt	1	11.1
Knowledge of curriculum organization	KoCO	2	22.2
Knowledge of teaching	KoT	3	33.3

Knowledge of assessment	KoA	1	11.1

Taylor's comments connected to multiple components of PCK. Their teaching choices demonstrated their KoCO and KoT, which revealed improved PCK quality. By sharing the purpose behind their lesson, they conveyed their KoG. They described their desire to integrate more assessments into their lesson (KoA), while also describing students' anticipated reactions to the content (KoSt). Taylor reiterated the content knowledge gains they experienced in CHEM 770 (KoSc).

Codebook 4

Codebook 4 was used to demonstrate the motivations behind the teacher's comments. These coding frequencies are shown in Table 118 below.

Table 118. Pre-Observation Survey Coding Frequencies for Observation 4 – CB4

Code	**Abbreviation**	**Frequency of Responses (*N* = 7)**	**Percentage of Total Responses (%)**
Learning-focused	L-f	1	14.3
Student-focused	S-f	1	14.3
Teaching-focused	T-f	5	71.4

Taylor shared comments primarily motivated by their teaching (71.4%), but they also gave single comments related to their own learning and their students' learning.

Teaching Observation

All teaching observations were conducted via Zoom. During Taylor's fourth semester in the program, I conducted their fourth and final teaching observation to assess their current level of teaching effectiveness and active PCK due to any program impact. During the observation, I took notes guided by the Instruction domain of the Danielson Framework for Teaching Evaluation Instrument.[62] The notes of the teaching observation were then analyzed using Codebook 2. Codebook 2 coding frequencies can be found in Table 119.

Table 119. Observation 4 Coding Frequencies – CB2

Code	**Abbreviation**	**Frequency of Responses (*N* = 37)**	**Percentage of Total Responses (%)**
Knowledge of goals	KoG	8	21.6
Knowledge of curriculum organization	KoCO	2	5.4
Knowledge of teaching	KoT	16	43.2
Knowledge of assessment	KoA	8	21.6
Knowledge of resources	KoR	3	8.1

KoG

Throughout their observed lesson, Taylor gave several real-world examples of topics related to electron configuration. They also made multiple analogies to these topics using real-world connections. During the lesson, Taylor expressed the purpose of learning quantum chemistry topics, focusing on students' ability to interpret scientific theories and data. They also shared the relevance of these topics for future college courses.

KoCO

Taylor shared their KoCO by communicating what content they will cover in their lesson and asking students to recall information learned earlier in the school year, allowing them to make connections between concepts.

KoT

Taylor began the lesson by asking students to recall what they learned in the previous class and earlier on in the school year. They clearly communicated their intentions for student learning and employed multiple teaching strategies to approach the concept of electron configuration in multiple ways. Although much of the lesson was direct instruction, they involved students in discussions and practice problems. They rephrased their questions multiple times to allow students to continue thinking about the concepts in new ways. Similarly, their questioning methods probed for deeper understanding of the content. They made corrections to students' answers when relevant. Their combination of KoT and KoA revealed higher quality PCK. They communicated their teaching approach and use of scaffolds to students, demonstrating the transparency of their instruction.

KoA

Taylor assessed student understanding throughout the lesson by direct questioning and probing for deeper understanding. They asked students questions about their prior knowledge to evaluate their retention. They utilized cold calling methods to involve multiple students in the discussion of practice problems. They involved students in their instruction by asking students to make predictions and, through this process, they were able to identify any misconceptions that arose during the lesson.

KoR

Taylor demonstrated their KoR by incorporating several visual resources into their instruction, including multiple simulations.

Post-Observation Survey

Once I was notified that the Zoom observation was complete, I sent Taylor the post-observation survey by email. The post-observation survey was coded using Codebooks 1, 2, and 4.

Codebook 1

Codebook 1 coding frequencies are shown in Table 120.

Table 120. Post-Observation Survey Coding Frequencies for Observation 4 – CB1

Code	**Abbreviation**	**Frequency of Responses (*N* = 11)**	**Percentage of Total Responses (%)**
Attitudes	A-c	1	9.1
Teaching	T	7	63.6
Reflection	R	3	27.3

Attitudes (A-c)

Taylor detailed which aspects of their teaching allowed them to feel confident that student learning took place. By combining their KoT and KoSt, Taylor demonstrated higher quality PCK.

- "Due to the time I allocated and the nature of the weirdness of quantum ideas, I left feeling confident that they at least understood the rationale I tried to establish about why the quantum model needed to be created. Though we were only able to go over some of the most basic aspects of electron configuration, I also felt confident about their learning in that limited context."

Teaching (T)

Taylor detailed how the carried out their observed lesson. They first discussed the topics they were able to cover and how they fit into their overall unit, demonstrating their KoCO. By combining their KoT and KoCO, Taylor displayed higher quality PCK.

- "I was more than fine with how [the lesson] played out given the fact that we were able to have an interesting conversation about quantum ideas and began to introduce ideas like atomic orbitals and the relationship between the periodic table and electron configuration. This provided a nice foundation for the following day and far less frontloading of ideas was needed."

Taylor hoped to make the discussion of quantum chemistry more student-centered, which revealed their teaching philosophy.

- "With respect to the initial quantum ideas discussion, I would make this a more focused conversation and actually see if I can find ways to involve [students] more."

Taylor then discussed a new activity they would like to bring into their instruction. By combining their KoT and KoR, Taylor demonstrated improvements to their PCK quality. Otherwise, they did not plan to make any changes to this lesson.

- "Though I sort of did this the previous day by having them work on a photospectroscopy [sic] activity that generated evidence for there being more complexity to the structure of the atom than simply energy levels, I think I'd like to stich an inquiry-based activity like that with a primer on atomic orbitals. Once orbitals and how they are filled were established, I wouldn't really change my approach to how I structured the content delivery."

Summary of Teaching (T)

Taylor discussed how their lesson went and what changes they intend to make in the future. The main themes for teaching were:

- Taylor hoped to include more student-centered discussion about quantum chemistry in the future. They also hoped to implement an inquiry-based activity, again placing students at the center of the learning process. By combining their KoT and KoR, Taylor displayed higher quality PCK.

- Displaying their KoCO, Taylor discussed how their observed lesson provided students with necessary foundational knowledge for the remainder of the unit. This combination of their KoT and KoCO demonstrated improved PCK quality.

Reflection (R)

Taylor reflected that the lesson went as expected "for the most part," but stated that they dwelled on the introduction to quantum topics longer than anticipated.

- "Looking back, I wish I wasn't so easily wrapped up in the initial quantum conversation. I know I get excited just discussing it but that can easily turn into 30 minutes when the point of emphasis I was trying to address may have been sufficiently made 15 minutes prior."

They also reflected on how they would change their lesson to integrate more student involvement. This statement reveals both Taylor's teaching philosophy and improvements to their PCK through improved KoT.

- "With respect to how I covered atomic orbitals and the initial part of electron configuration, I would tweak it slightly. The content itself is fine but I'd like students to play more of an integral part in the generation of questions that would ultimately reveal a clear need for there to be something more explanatory than the Bohr model."

Codebook 2

Codebook 2 coding frequencies can be found in Table 121.

Table 121. Post-Observation Survey Coding Frequencies for Observation 4 – CB2

Code	**Abbreviation**	**Frequency of Responses (*N* = 19)**	**Percentage of Total Responses (%)**
Knowledge of students	KoSt	5	26.3
Knowledge of curriculum organization	KoCO	4	21.1
Knowledge of teaching	KoT	6	31.6
Knowledge of assessment	KoA	4	21.1

Taylor's responses to the post-observation survey reflected their possession of four components of PCK. They expressed their KoT, KoCO, KoA, and KoSt by discussing their observed lesson and assessing how it could be improved for the future, which demonstrated improvements to their PCK. Taylor displayed their KoSt by discussing students' reactions to their instruction of quantum chemistry. They felt that emotional reactions may not indicate content understanding.

- "Though students may be surprised by things like the double-slit experiment, it doesn't necessarily mean they were able to make that conceptual leap with me when discussing the impact of the electron exhibiting wave-like behavior."

Furthering their discussion of students' reception of their lesson, they described the intended learning outcomes for the lesson. They described their KoA by sharing how they informally assessed student understanding.

- "I wanted them to have a basic enough understanding of atomic orbitals, how they are filled, and how we symbolically communicate where electrons are in the atom. Based on the responses I got from a variety of students who were asked questions throughout the lesson, I felt they received the lesson fairly well; at least well enough to have a strong foundation for the following day."

Taylor demonstrated their KoA and KoSt when describing confusion they noticed in their students, which revealed improved PCK quality. They discussed their lesson, intended learning outcomes, and observations of student misconceptions. Taylor assessed student understanding by involving students in the whole class discussion and evaluating their responses for any misconceptions.

- "There was undoubtedly confusion throughout the mini-discussion surrounding the double slit experiment and the implication of such results. However, this confusion was anticipated and was not going to have an immediate negative impact on the extent to which I wanted them to demonstrate understanding of electron configuration that day. Confusion was largely identified by the types of predictions they made regarding the electron's behavior and even some of the questions they asked that made their confusion more explicit."
- "Given the lack of depth I knew we were going to get to for that lesson regarding electron configuration, I didn't really expect much confusion and felt fairly confident that confusion wasn't present in any concerning way considering the

number of students that contributed their answers toward fleshing out some of our early electron configuration problems."

Codebook 4

Codebook 4 was used to demonstrate the motivations behind the teacher's comments. These coding frequencies are shown in Table 122 below.

Table 122. Post-Observation Survey Coding Frequencies for Observation 4 – CB4

Code	**Abbreviation**	**Frequency of Responses (*N* = 13)**	**Percentage of Total Responses (%)**
Student-focused	S-f	6	46.2
Teaching-focused	T-f	7	53.8

Taylor's responses to the post-observation survey were split between teaching-focused (53.8%) and student-focused (46.2%) motivations.

Summary of Observation 4

Taylor's fourth and final progress observation focused on electron configurations and quantum theory. The main themes from Observation 4 were:

- Taylor shared positive attitudes toward the content of their observed lesson, which led them to spend more time on these topics than anticipated. They discussed wanting to limit their introduction to quantum theory in the future, demonstrating their ability to evaluate their own teaching.

- Prior to the lesson, Taylor had no concerns with their students' ability to understand the content. During the lesson, they checked for understanding (KoA) and determined that any anticipated confusion was related to their discussion of the double-slit experiment. By combining their KoT and KoA, Taylor displayed higher quality PCK.
- Taylor determined that students met their intended learning outcomes for the lesson, which meant they developed good foundational knowledge for electron configurations and orbital diagrams. They also gave students opportunities to recall information learned earlier in the course (KoCO). This combination of their KoSt and KoCO revealed improvements to their PCK quality.
- When considering changes they would make to their lesson in the future, Taylor hoped to integrate more student involvement into the class discussions. This again aligned with their student-centered teaching approach.
- Taylor demonstrated their KoR by utilizing several visual resources in their instruction of the double-slit experiment, including multiple simulations.
- Throughout their instruction, Taylor incorporated several real-world connections through the use of analogies and examples that made the content more relevant for students, demonstrating both their KoG and KoSt. This combination of knowledge bases revealed higher quality PCK.

Taylor's comments before and after the lesson were mostly focused on their teaching motivations (60%), while the remaining statements were motivated by their students' learning (35%) and their own learning (5%) that had been impacted by the CHEM 770 course.

End-of-Semester Survey

At the end of the Spring 2023 semester, I sent out an email invitation to participants of CHEM 773 to complete a survey about their experiences in core MS program courses and the MS program overall during the given semester. Taylor's responses to this survey were coded with Codebooks 1, 3, and 4.

<u>*Codebook 1*</u>

Coding frequencies for Codebook 1 can be found in Table 123.

Table 123. End-of-Semester Survey Coding Frequencies for Semester 4 – CB1

Code	**Abbreviation**	**Frequency of Responses (*N* = 25)**	**Percentage of Total Responses (%)**
Attitudes	A-c	3	12
Knowledge	K-p	1	4
	K-c	6	24
Skill	S-c	2	8
Teaching	T	3	12
Feedback	F	4	16
Modules	M	1	4
Interaction	I	2	8
Reflection	R	3	12

Attitudes (A-c)

Taylor described improvements to their confidence and comfort levels resulting from their interaction with CHEM 773 topics. By increasing their KoSc, Taylor experienced improvements to their overall PCK.

- "Practicing these problems and studying them [through homework and exams] gave me more confidence to navigate problems within equilibrium."
- "I actually feel way more comfortable talking about and teaching these topics now."

They also shared positive attitudes toward their interactions with instructors for the MS program. These interactions supported Taylor's PCK and professional development.

- "I've really appreciated how supportive, flexible, and knowledgeable all the professors have been. It's made this online learning environment a really great experience."

Knowledge (K-p and K-c)

Taylor discussed how the CHEM 773 course impacted their knowledge of equilibrium and acid-base chemistry, stating that the course filled gaps in their KoSc. By improving their KoSc, Taylor experienced improved PCK through the CHEM 773 course.

- "Though I felt reasonably competent in both acid/base and equilibrium content knowledge, I knew that I had gaps in understanding that prevented me from getting to a more comfortable state. This course helped me close those gaps and think about such topics in ways I hadn't previously considered."

Taylor described improving their chemistry content knowledge (KoSc) in the CHEM 773 course, especially related to the content they teach. By combining their KoCO and KoSc, Taylor demonstrated improved PCK quality.

- "I dramatically improved my content knowledge of these topics [and] became aware of new ideas and activities."
- Their chemistry content knowledge "has improved quite a bit."
- "I know more about the subjects I'm trying to teach."

When reflecting on the discussion forums, Taylor stated that they typically didn't gain content understanding. Although they gained KoSc as a component of their PCK, the discussion forums did not improve the quality of their PCK.

- "Though I learned all kinds of new information about the topic of equilibrium in the discussion forums, this information rarely helped me better understand the underlying concepts within equilibrium."

They then discussed improvements to their pedagogical skill via increased knowledge of equilibrium ideas. By combining their KoT and KoSc, Taylor demonstrated improved PCK quality.

- "I think any effect [the CHEM 773 course] may have had on my pedagogical skill has to do with the exposure to new ideas and connections that I had with respect to equilibrium."

<u>Summary of Knowledge (K-p and K-c)</u>

Taylor shared how their content and pedagogical knowledge had been impacted by the CHEM 773 course. The main themes for knowledge were:

- Taylor indicated large improvements to their chemistry content knowledge, stating that the CHEM 773 course filled gaps in their content understanding. They specifically discussed gaining KoSc of the content they teach, indicating improvements to their PCK. By combining their KoSc and KoCO, Taylor demonstrated improved PCK quality.
- Taylor gained pedagogical knowledge through the exposure to "new ideas and connections" related to equilibrium topics. By combining their KoT and KoSc, Taylor displayed improved PCK quality.
- From Taylor's perspective, the CHEM 773 discussion forums primarily led to teaching gains rather than improvements to chemistry content knowledge. Although they did gain some KoSc through the discussion forums, this information did not improve their overall content understanding of equilibria topics.

<u>Skill (S-c)</u>

Taylor first described improvements to their mathematical and problem-solving skills, which indicated improved KoSc as a component of their PCK.

- "My mathematical reasoning and general approach to mathematical problems have improved."

Taylor described improvements to their pedagogical skill by connecting content to instructional resources, indicating improved PCK quality through their KoT and KoR.

- "I now have a stronger awareness of ways I can connect these topics to various activities."

Teaching (T)

Taylor described gaining ideas through the discussion forums relating to new approaches for teaching equilibrium topics. By enhancing and combining their KoT and KoR, Taylor experienced improved PCK quality.

- "As a teacher, any time I was exposed to other ideas and connections to equilibrium, it created new potential activities and connections I could make with my own class. This was primarily done in the discussion forums."

They further emphasized their intention to bring new ideas learned in the CHEM 773 course into their instruction. This combination of their KoSc and KoT would improve the quality of their overall PCK. They predicted that the implementation of these ideas could improve their teaching effectiveness.

- "The exposure I got to new ideas within these topics was really valuable and I intend to integrate some of these ideas in the future."
- "Such ideas [from the CHEM 773 course] will allow me to potentially improve my instruction and make it a more meaningful learning experience when teaching equilibrium."

Feedback (F)

Taylor shared four comments coded as feedback. These statements were further analyzed using Codebook 3, which will be shared in the section below.

Modules (M)

The CoRe assignment allowed Taylor to reflect on their teaching of a CHEM 773 topic and improve their instruction for the future. The CoRe supported improvements to Taylor's KoT, which indicated improved PCK.

- “Reflecting on my own ability to teach a certain concept during the CoRe helped me better think about how I intend to teach this in the future.”

Interaction (I)

Through their experience in the MS program in Semester 4, they formed new connections with other teachers in the MS program.

- They “created new connections with other passionate teachers.”
- “I've gained new connections with teachers I would've otherwise never met.”

Reflection (R)

Taylor reflected on their experience in the MS program during Semester 4. They shared the learning value of working through problems on homework assignments and exams.

- “As a learner, the meaningful things to me were whenever I had to get my hands dirty and dive right into the problems, like in the homework sets and exams.”

They reiterated the value of the discussion forums for providing new connections and ideas that could be used in their teaching. Thus, the discussion forums enabled Taylor to improve their KoSc and KoT as components of their overall PCK.

- “Instead [the discussion forums] helped me more as a teacher to establish new connections and ideas I had previously been unaware of.”

Taylor discussed their enjoyment of a CHEM 773 assignment in which teachers wrote a chapter about an equilibrium topic.

- “The creativity surrounding the equilibrium ‘book’ idea was pretty cool. I didn't really expect to do something like that.”

Codebook 3

Taylor shared four comments coded as “Feedback.” These statements were further analyzed using Codebook 3. These coding frequencies are shown in Table 124 below.

Table 124. End-of-Semester Survey Coding Frequencies for Semester 4 – CB3

Code	**Abbreviation**	**Frequency of Responses (*N* = 4)**	**Percentage of Total Responses (%)**
Assignment Feedback	AF	1	25
Program Feedback	PF	2	50
Logistical Feedback	LF	1	25

Assignment Feedback

Taylor enjoyed the equilibrium book assignment and hoped to see the compiled submissions from their peers.

- “The creativity surrounding the equilibrium ‘book’ idea was pretty cool. I didn't really expect to do something like that, and I'd love to get a look at all the submissions together.”

Program Feedback

Taylor stated that their Semester 4 experience in the MS program was aligned with their expectations.

- “Going into my last semester, I pretty much knew what to expect. So, I can't really say anything that didn't meet my expectations.”

Taylor also shared positive feedback about the MS program instructors.

- “I've really appreciated how supportive, flexible, and knowledgeable all the professors have been. It's made this online learning environment a really great experience.”

Logistical Feedback

When asked what they would change to improve the MS program, Taylor reiterated their desire for online practice problem software that provides immediate feedback.

- “Integrating some kind of online practice software that allows students to practice certain problems that provide immediate feedback.”

Codebook 4

Codebook 4 was used to analyze Taylor’s motivations for statements made in the end-of-semester survey. Coding frequencies can be found in Table 125.

Table 125. End-of-Semester Survey Coding Frequencies for Semester 4 – CB4

Code	**Abbreviation**	**Frequency of Responses (*N* = 14)**	**Percentage of Total Responses (%)**
Learning-focused	L-f	8	57.1
Teaching-focused	T-f	6	42.9

Taylor's responses to the end-of-semester survey were split between learning-focused (57.1%) and teaching-focused (42.9%) motivations. They did not share any statements motivated by implications for student learning. An example of each code is given below.

- "Though I felt reasonably competent in both acid/base and equilibrium content knowledge, I knew that I had gaps in understanding that prevented me from getting to a more comfortable state. This course helped me close those gaps and think about such topics in ways I hadn't previously considered." (L-f)
- "As a teacher, any time I was exposed to other ideas and connections to equilibrium, it created new potential activities and connections I could make with my own class." (T-f)

<u>Summary of End-of-Semester Survey</u>

Taylor's responses to the end-of-semester survey were motivated by MS program gains related to their learning (57.1%) and teaching (42.9%). The main themes from this survey were:

- Taylor described dramatic improvements to their chemistry content knowledge (KoSc), stating that the CHEM 773 course filled gaps in their content understanding. Their improved KoSc led to improvements to their pedagogical skill (KoT), indicating improved PCK quality.
- By gaining confidence with CHEM 773 content, Taylor became more comfortable teaching these topics, which has implications for improved teaching effectiveness. This combination of their KoSc and KoT indicated improved PCK quality.

- The CHEM 773 discussion forums helped Taylor establish new connections between equilibrium content (KoSc) and their teaching (KoT), demonstrating improved PCK quality.
- Taylor gained new connections with teachers in the MS program during Semester 4 and shared their appreciation for MS program instructors.
- Taylor shared positive feedback about the CHEM 773 equilibrium book assignment, as well as the support they received from MS program instructors. They emphasized the value of online homework software with immediate feedback for their learning.

Summary of Semester 4

During Semester 4, Taylor participated in the sixth check-in interview, the CoRe and its module survey, their fourth and final progress observation and its surveys, and the end-of-semester survey. The main themes for their fourth semester in the MS program were:

- In their CoRe module survey, sixth check-in interview, and end-of-semester survey, Taylor described improvements to their chemistry content knowledge (KoSc) through the CHEM 773 course, which improved their overall PCK. Filling gaps in their KoSc improved Taylor's confidence and led to improvements in their pedagogical skill (KoT). By combining their KoSc and KoT, Taylor demonstrated improvements to their PCK quality. They applied new knowledge to their teaching, which demonstrates an impact of the MS program on their teaching effectiveness and overall PCK quality.

- The CHEM 773 discussion forums and teacher-initiated study groups helped Taylor establish new connections between chemistry content (KoSc) and their teaching (KoT), which aided their development of higher quality PCK. These learning methods highlighted the importance of interpersonal connections during the MS program.
- In their CoRe and teaching observation, Taylor combined all PCK bases when planning and executing a lesson on equilibria and acid-base chemistry topics. Taylor's lesson plans involved student-centered learning activities, scaffolding, modeling, and assessment methods. Taylor reflected on each lesson to determine how to improve their future instruction to benefit student learning.
- Taylor reflected on their recent professional burnout due to the demands of the MS program, their teaching, and their family life. They described being in "a better place" at the start of Semester 4 due to the more manageable workload and support via teacher-initiated study groups.
- Taylor's goals for the remainder of their MS program experience were to complete their content course requirements – which they accomplished at the conclusion of Semester 4 – and prepare, execute, and defend their action research project.
- In Semester 4, Taylor demonstrated the presence of all seven components of PCK. The intertwining of these knowledge bases revealed improvements to the overall quality of their PCK.
- Taylor shared positive feedback regarding support they received from MS program instructors, as well as the incorporation of books into MS content

courses, including the equilibrium book assignment in CHEM 773. They emphasized the value of an online homework software with immediate feedback. They hoped for more video lectures from their instructors and uniformity across courses in terms of weekly communications.

Summer 2

During the second summer session, Taylor returned to the SDSU campus for a two-week session. The CHEM 776 course again focused on the development of laboratory activities in conjunction with a laboratory research experience with SDSU research faculty and graduate students. Other courses were also available to the MS participants related to waste disposal, green chemistry, and chemical demonstrations; however, Taylor did not take part in these courses. All MS program courses extended past the on-campus segment, but the majority of data collection focused on the on-campus experience. Table 126 summarizes the methods used during the summer session.

Table 126. Summer Data Collection Methods

Term	**Data Collection Methods**	**ID Codes**
Summer Sessions	**Before campus:**	
	Check-in Interview 7	I
	ASCI (pre)	ASCI
	Summer Journal #1	SJ
	On campus:	
	Summer Journal #2	SJ
	After campus:	

	Summer Journal #3	SJ
	ASCI (post)	ASCI
	Post-campus summer survey	PCSS
	End-of-summer survey	EOS

Check-in Interview 7

At the start of the summer session, I interviewed Taylor via Zoom to learn more about their experience in the MS program during Semester 4 and their goals for their second and final summer on campus. The seventh check-in interview was coded using Codebooks 1, 3, and 4.

<u>*Codebook 1*</u>

Codebook 1 coding frequencies are shown in Table 127.

Table 127. Check-in Interview 7 Coding Frequencies – CB1

Code	**Abbreviation**	**Frequency of Responses (*N* = 83)**	**Percentage of Total Responses (%)**
Attitudes	A-p	1	1.2
	A-c	9	10.8
Knowledge	K-c	4	4.8
Skill	S-c	6	7.2
Goals	G	6	7.2
Experience	E	11	13.3

Background	B	3	3.6
Feedback	F	6	7.2
Teaching	T	7	8.4
Interaction	I	4	4.8
Reflection	R	26	31.3

Attitudes (A-p and A-c)

Taylor described their lack of confidence in acid-base chemistry prior to gaining knowledge (KoSc) through the CHEM 773 course. Gaining KoSc led to improvements to Taylor's overall PCK.

- Gaining knowledge of acid-base chemistry in CHEM 773 "was big for me because I just didn't feel that confident about it."

Taylor discussed feeling proud of the effort they put into the MS program courses in order to succeed.

- "Now that I pretty much finished my last semester, I'm really proud of the amount of work that I've needed to put into something to get the result that I got. I've gotten an A in classes before where I didn't really do anything, and I felt like I had to work at this."

They also described improvements to their teaching confidence resulting from incorporating ideas and knowledge from the MS program. These experiences also improved their confidence as a chemist.

- Incorporating ideas from the MS program "has made me feel a lot more confident as a teacher and as a knower of chemistry."

Taylor reflected on their comfort level toward returning to campus for their second summer.

- "I'm feeling more comfortable coming into this summer, obviously because you've got one under your belt and you kind of know what to expect, and you're aware of some people and things like that, so there's that familiarity aspect."

Taylor shared anxious feelings related to completing the MS degree.

- "I think there's naturally this in the back of my mind this anxiety regarding the finishing up the things with the Master's, like, 'what if I did all this stuff and then I ended up not doing well on this?'"

When looking forward to the coming term, Taylor stated that they were "excited for this summer."

<u>Summary of Attitudes (A-p and A-c)</u>

Taylor shared attitude changes that occurred throughout their experience in the MS program. The main themes for attitudes were:

- Taylor gained confidence in their acid-base chemistry knowledge through the CHEM 773 course.
- Applying ideas and knowledge from the MS program to their instruction allowed Taylor to develop confidence as a teacher and as a chemist.
- Taylor felt excited to return to the SDSU campus for their second summer and felt comfortable doing so due to their first summer experience.
- Although Taylor felt proud of the work they accomplished through the MS program, they reported feelings of anxiety related to successfully completing the degree.

Taylor's improved confidence in their KoSc led to improved PCK.

Knowledge (K-c)

After Semester 4, Taylor stated that they "feel a lot more knowledgeable." In terms of knowledge gains, Taylor discussed knowledge gained from the CHEM 773 course (KoSc), which focused on equilibria and acid-base chemistry topics. This gain of KoSc led to improved PCK. They also shared an experience of being able to apply this new knowledge to their professional context. By combining their KoSc and KoT, Taylor demonstrated improved PCK quality.

- In CHEM 773, "I actually learned quite a bit of new things, applications of things, especially in the context of equilibrium. I really buffed up my acid-base understanding, definitely like pH of salts or acid-base properties of salts, weak acid-base stuff…And so just the other day a colleague of mine came in and he was like 'I'm looking for like a weak base' and I was like, 'oh, you could use sodium acetate because acetate is blah blah blah,' and I just would not have said that a year ago."

When discussing why they think the summer is a meaningful component of the MS program, Taylor discussed the value behind "the exposure to the lab setting."

- "Being able to work on techniques and being able to expose yourself to equipment that you would never have and bring that knowledge back to you in some shape or form" is meaningful.

Summary of Knowledge (K-c)

Taylor gained chemistry content knowledge from the CHEM 773 course that they were able to apply in a professional setting. They also discussed gaining practical laboratory knowledge during the campus research experience. They demonstrated improved PCK quality by applying knowledge gained in the MS program (KoSc) to their teaching (KoT).

Skill (S-c)

Taylor described improvements to their lab and pedagogical skills through the MS program. First, they discussed improvements to their pedagogical skill (KoT), which indicated improved PCK. They were able to approach more complex topics in their classroom due to increased KoSc. This combination of their KoSc and KoT demonstrated improved PCK quality.

- “I feel…more capable at approaching more complex topics.”

When reflecting on their first summer experience, they discussed exposure to new lab techniques, which improved their laboratory skill. They discussed being aware of new techniques, instrumentation, and software. By increasing their KoSc, Taylor enhanced their overall PCK.

- “That whole lab experience was just so cool. It was so good. I tried so many different things. I got exposed to so many different techniques or approaches.”
- “That exposed me to equipment. Spec, definitely.”
- “There are more advanced techniques that I just wouldn't have been aware of otherwise. And the role that software can play in things.”

Overall, they described improvements to their lab skill and knowledge. This improvement to their KoSc indicated improved PCK.

- “The equipment features in the lab setting is something that I think I definitely got better at and was more cognizant of.”

They then applied their knowledge of instrumentation (KoSc) to their teaching (KoT), demonstrating improved PCK quality due to the summer campus research experience.

- “If you can't literally integrate [knowledge of equipment] with that machine, you could talk about it in ways that are relevant and bringing back other techniques.”

Summary of Skill (S-c)

Taylor gained laboratory and pedagogical skills through their experience in the MS program. The main themes for skill were:

- In terms of pedagogy, they described their improved capacity to approach “more complex topics” in their classroom. By combining their KoSc and KoT, Taylor demonstrated improved PCK quality.
- Through the summer research experience, they were exposed to new laboratory techniques, equipment, and software, which improved their overall lab skill. Improved KoSc indicated improved PCK.
- They planned to bring back new knowledge and skill gained in the research lab to their teaching, demonstrating improved PCK quality resulting from the intertwining of their KoSc and KoT.

Goals

Taylor reflected on their overall goals for the MS program, stating that they did not aim to change their pedagogy.

- “I did not go into [the MS program] trying to get massive advancements or some revolutionary change in my pedagogical things.”

In terms of their goals for their second summer, they reflected on their hopes for the laboratory research experience. They discussed being “torn between” their desire to return to the same research lab from Summer 1 and their hope to be exposed to a new research lab.

- "I want to do the same thing that I did do last summer because I want to be in the same context that I was last summer. I don't have to literally do the same thing, but to have that freedom. At the same time, I think there's some cool ideas and other professors to work with that I should expose myself to more things."

In terms of their goals for completing the MS degree, they shared their plans for their defense.

- "I don't know this for a fact, but I think I would plan on defending in July."

To prepare for their defense, Taylor shared their goal to make progress on their action research paper prior to arriving on campus.

- "That's going to push me from now until [arriving on campus] to really make some huge progression on" their action research paper.

To conclude the interview, Taylor shared how this goal would allow them to focus on CHEM 776 while on campus.

- "I don't want to be in a scenario where I come to SDSU for those 2 weeks and I'm constantly stressed in the back of my mind about the paper. I don't want to do that. I saw some people last summer how they were, and I just want to focus on whatever we're doing here, focus on that stuff and not have to worry about that."

Summary of Goals

Taylor first shared that changing their pedagogy was not a goal they had for their time in the MS program. They did, however, identify their personal goals for the remainder of their experience in the MS program:

- In terms of their second campus experience, Taylor hoped to either return to the same research lab or expose themselves to new ideas in a different professor's lab.
- They hoped to make progress on their action research paper prior to arriving on campus so that they could focus solely on CHEM 776.
- They hoped to defend their action research project in July after the summer campus experience.

Experience

Taylor shared various experiences that took place during their time in the MS program. They first discussed their overall experience in Semester 4, reflecting primarily on the CHEM 773 course. They talked about a shift in their course engagement compared to previous semesters due to other professional and personal obligations.

- CHEM "773, the equilibrium class, went well. It was the first time that I participated a lot less in the video sessions, which was more so a function of baseball [coaching] and now having a new baby in the family, whereas that wasn't the case the same time last year. It wasn't a function of the class itself because I like attending those Wednesday meetings, but I would still try to make as many of the Sunday night [teacher-initiated study groups] and those are helpful for sure. It was also probably the first time where I relied more so on the book and the paper rather than the instruction coming from Instructor A. I think part of that may have been familiarity with certain topics, like equilibrium and acids and bases. Part of that again was just time. I just didn't have time to watch this 45-minute lecture. I think overall it was good."

They discussed their experience writing their chapter for the equilibrium book assignment in CHEM 773.

- "In my case I was talking about the Flint water crisis and so it was just how do you sort of tell a story rather than 'here is exactly what happened'?"

Taylor described their experience so far in the Summer 2 iteration of CHEM 776. They detailed a discussion on digital badging that allowed them to further develop their KoT as a component of their PCK.

- "I like the lab development class. Just the other night talking about digital badging and things I hadn't really thought too much about but can make connections to what I'm doing" allowed them to reflect on their pedagogy.

They further described the shift in their attitudes toward the use of digital badging in the high school classroom due to the discussions in CHEM 776.

- "I've obviously heard of digital badging, but the paper we were reading, and then what we were talking about had me seriously considering it. It always felt super elementary/middle school to me."

When reflecting on an activity they planned to bring into their classroom, they talked about their experience performing a caffeine extraction in their Summer 1 research lab.

- The caffeine extraction "wasn't a specific activity per se, as it was an experience that I had that wasn't directly affiliated with any of the professors per se. It was kind of what we did on the side from the Vitamin C stuff."

While in their Summer 1 research lab, Taylor learned how to use a vacuum pump to perform vacuum filtration, which they planned to integrate into their own classroom. By applying new KoSc to their KoT, Taylor demonstrated improved PCK quality.

- “It wasn't until I was in the lab last summer that I saw them basically the same vacuum that I have and they’re like, ‘yeah, we just plug it in and do vacuum filtration that way. It's one way to do it.’”

Taylor described their Summer 1 GTA’s encouragement of their exploration in the lab. Thus, interactions with their GTA supported their development of KoSc as a component of their PCK.

- “I really liked the informality of it. [The GTA] was very good at allowing us [to explore] – because we would want very specific instructions like ‘should I do this? Am I doing the right thing?’ And they’d be like, ‘Oh, you should just try it.’”

Taylor described the value of the summer campus experience in terms of connections with other MS program participants. Being in person allowed for improved discussions. This statement was also coded as “Interactions.”

- “When we meet in those mornings to discuss certain papers, we could do that exact same thing via Zoom, but it's so much different in person. There's so much more back and forth. There's so much more constructive argumentation between people. People seem to be more willing to butt heads, which I like, and toss ideas around that we just couldn't do in an online setting or that people feel less comfortable doing in an online setting.”

Taylor compared their previous summer experience in terms of making progress toward their research to the upcoming summer. They shared positive attitudes (A-c) toward making progress on their action research project now that they are near the end of data analysis. Taylor then reflected on their experience during Summer 1 and Semester 3 attempting to make research progress while juggling other responsibilities.

- “With the last couple of weeks of school remaining, I’m meeting tomorrow with Instructor B. It's going to be kind of the final stages of analysis and now I just need to start to ‘Okay, how does all this analysis fit into this this thing that I'm building’ and I'm finally excited to start to dive a lot deeper into the background of the research that I'm doing because I had the time at the end of the summer last year to do that with stoichiometry, but then I messed that up. Once school started it was way harder, especially with these [MS program] classes also happening the same time, it's super hard. It just became way more difficult to be like, ‘I'm going to spend an hour here, an hour there researching educational research regarding bonding’”

Summary of Experience

Taylor shared various experiences that occurred during their enrollment in the MS program. The main themes for experience were:

- Taylor discussed their experience in Semester 4, focusing on finding balance between the CHEM 773 course, their family life, and coaching. They shared that their lack of time led them to focus on more independent learning in the MS program course rather than attending optional Zoom meetings for the course.
- The CHEM 776 online discussions allowed Taylor to reflect on their pedagogy by introducing new ideas, therefore increasing their KoR as a component of their overall PCK.

- Taylor planned to bring new laboratory procedures and equipment into their classroom resulting from their research experience in Summer 1. They hoped to apply their experience with a caffeine extraction in an SDSU research lab to their own instruction.
- Taylor discussed how their GTA encouraged independence in the research lab during Summer 1, which Taylor appreciated. Their GTA supported improvements to Taylor's KoSc as a component of their PCK.
- Taylor described improved argumentation and comfort during in-person CHEM 776 discussions compared to Zoom discussions.
- Taylor reflected on their experience shifting topics for their action research project due to logistical challenges in Semester 3, emphasizing the challenge of making research progress while balancing other obligations.

<u>Background</u>

Taylor reflected on experiences that led them to the MS program. They heard about a recommendation for the MS program while on the SDSU campus for a conference four years prior to their enrollment.

- "I had heard good things about it from somebody that I met at Chem Ed in 2017 when it was at SDSU."

In terms of their teaching context, Taylor discussed their department's need for updated laboratory equipment.

- "We were seriously lacking as a department in terms of our equipment, and so we made a big push through Vernier or Pasco to get all kinds of sensors and probes."

Taylor confirmed that this acquisition of equipment was recent and explained the circumstances that allowed for these purchases.

- "This year we have thousands of more dollars of probeware and it happened to be coincidental that [the] science [department] was up for a curricular allocation of funds within the school every X years. but it was like, 'okay, let's jump with that' and so that's been pretty cool. Definitely, it's beefed things up and allowed us to do things that we weren't able to do otherwise."

Summary of Background

The MS program was recommended to Taylor by a colleague at a chemical education conference four years prior to their enrollment. In part inspired by their Summer 1 research experience, Taylor discussed their department's acquisition of new lab equipment, including new sensors and probeware.

Feedback

Taylor shared six comments coded as feedback. These statements were further analyzed using Codebook 3, which will be shared in the section below.

Teaching

Taylor discussed how their development of new KoSc through the CHEM 773 course forced them to focus on their KoCO, KoSt, and KoT. They were required to alter their explanation of equilibria and acid-base topics depending on the student learning context. Improving separate components of their PCK enabled them to reflect on and improve additional PCK bases, demonstrating improved quality to their overall PCK.

- "In fact, [feeling more knowledgeable] has almost created a problem for me because I have to remind myself that my students aren't grad students. We'll talk about titrating a weak acid with a strong base and it's like, ‘Okay, maybe they don't need to know the Henderson-Hasselbalch equation.’ It's not really necessary for what we're going to do and it's more of an issue at the Gen Chem level. I think it's allowed me to push my Honors Chem to another level to make it a little bit more rigorous and being able to explain things in various ways.”

When discussing Summer 1 takeaways that they hoped to bring into their classroom, Taylor stated that they “have integrated a lot of little ideas [and] some big ideas.” They detailed their plan to incorporate a caffeine extraction into one of their laboratory activities. They shared positive attitudes toward trying this organic chemistry procedure with their students. By combining their KoSc and KoT, Taylor demonstrated improved PCK quality.

- “I'm trying to work on this caffeine extraction which came solely as a result of working at SDSU last summer and doing that caffeine extraction. I don't know how it's going to go, but I have enough written down from last year that I think I can replicate it and hope I can get my students involved. I think it's going to be cool.”

Taylor then described an activity that they took from a fellow MS program participant during Summer 1. They detailed their experience incorporating this activity into their instruction. By combining their KoR and KoT, Taylor demonstrated improved PCK quality.

- “There was an intermolecular forces activity with these little beads [*shows beads*] and it was cool because we've been doing a lot more phenomena-based instruction and so before we started intermolecular forces I had made several of these and so

I shook it and I said, ‘Okay, so let's just be silent for a minute and watch what happens and write down any questions you have, things you wonder, things you notice.’ The kids actually came away with a whole bunch of cool observations. They could see that clearly there's a separation going on: ‘is it just a density thing?’ Clearly there's something going on there about these two liquids. And so that was a cool thing to make with the kids and it wouldn't have happened had it not been there that summer.”

In terms of bringing in knowledge from research labs, Taylor elaborated on how they planned to use existing equipment in their chemistry classroom. This improvement to their KoSc positively impacted their PCK.

- “I've had a vacuum pump forever and, because we don't have a vacuum thing in the fume hood, I’ve never done vacuum filtration here…[learning about using a vacuum pump for vacuum filtration] has broadened the applications we could do with that where gravity filtration would take way too long.”

They also described their acquisition of new laboratory equipment.

- “We just got 8 new spectrometers from Pasco… Now we have a melting [point] station. We put that in the budget and now we got it.”

Their experience in an SDSU research lab inspired them to purchase relevant equipment for their classroom, as described above, to carry out the same experiment with their students. By improving their KoSc, Taylor experienced enhanced PCK.

- “I remember when we isolated the caffeine and then were like, ‘well, caffeine should melt at [235-237]°C. Let's put it in the melting station, and that can allow us to detect for purity.’ Now we have a melting station and so that's ultimately what I'm going to have my kids do. Hopefully we can generate enough caffeine to get in a little capillary tube."

Summary of Teaching

Taylor discussed their application of new KoSc gained in the MS program to their teaching, demonstrating improvements to their KoCO, KoSt, KoT, and KoR which revealed improved PCK quality. The main themes for teaching were:

- Taylor adjusted the depth of their content explanations depending on the student learning context, demonstrating both KoCO and KoSt as components of their PCK.
- Taylor elaborated on their desire to bring back a caffeine extraction activity from their research lab experience in Summer 1. In addition to performing a caffeine extraction, their students could determine the melting point of caffeine using newly acquired laboratory equipment. Taylor also learned that they can use an existing vacuum pump in their classroom to perform vacuum filtrations. The campus research experience exposed them to techniques and procedures that they could apply to their own laboratory teaching approach involving new and existing equipment. Gaining and combining new KoSc and KoR improved the quality of Taylor's overall PCK.
- Taylor gained an intermolecular forces activity from a peer in the MS program, which they planned to integrate into their teaching. This improvement to their KoR led to improved PCK.

Interaction

Taylor reflected on the value of interacting with other MS program participants during the summer campus experience. These interactions allowed Taylor to develop KoT and KoR as components of their overall PCK.

- "There's a product of other people being there with me at the summer who brought ideas which I think is something that you get out of it, anyway. Part of the program, a built-in feature of it, is that just being with other people, you're going to naturally expose yourself to more ideas. So that's cool."

Connecting to their K-c, Taylor discussed the value of gaining knowledge alongside other teachers in the MS program. Interacting with other MS program participants supported Taylor's development of PCK.

- "Probably just the social aspect of it again…I like that it's a recognition that you're getting something out of this. It's hard to quantify. It's just having that experience. Having the experience, the things that you learn there, the relationships or the people that you meet."

Summary of Interaction

Taylor shared the value of interacting with other teachers through the MS program, especially while on campus. Taylor gained KoT and KoR through their interactions with other MS program participants, demonstrating improved PCK quality. Interacting with other MS program participants supported Taylor's development of PCK.

Reflection

Taylor first reflected on the equilibrium book assignment in CHEM 773. They related this experience to their own enjoyment of scientific storytelling, which related to books from other MS program courses and additional chemistry books they have read on their own time.

- "When it initially got pitched, I was like, 'it sounds kind of corny,' but then once I started doing it from my point of view, I started to realize how much I was learning from it. The fact that you had to try to come at it from a storytelling point of view because I thought [*In Search of Schrödinger's Cat*] and [*Strange Glow*] were so good [in MS program courses].[74, 75] I liked reading books like Sam Kean's *The Disappearing Spoon*.[76] It's about chemistry factual knowledge, but also in the context of larger narratives throughout history. That was fun to embody…That was fun from a creative point of view."

After sharing their experiences in the CHEM 773 course, Taylor reflected on the status of their action research project.

- "In the fall, I was not so much in a good place regarding research because I wasn't where I wanted to be. One thing led to another, and I basically missed my window for when the unit upon which my initial idea of research was going to occur. Long story short, I feel a lot better where I am now. I have the data, I've gone through some analysis, and so now I'm just wrestling with the inner workings of it, trying to always remind myself, 'what exactly am I asking here?' I find myself going down this rabbit hole and that rabbit hole of analysis, student data, and misconceptions. And I'm like, 'Okay, hold on, I could go into that, but it's not really relevant to what I'm asking.'"

They then reflected on how they could adjust their action research for the future. They reflected also on the reproducibility of chemical education research.

- "It's also blossomed some ideas for next year for if I had to do this again, how I would do that differently, which is good. I've had several conversations with Instructor B about this, where especially with educational research it's not so much 'here's what I did my class, and it worked. Therefore, it should work everywhere.' It's more so 'look in my little mini universe. I used to do this. I tried this. This went better, and I can make those changes to have a positive impact on the things that I teach.' I think some things are translatable, no doubt, but that's another thing that I'm trying to remind myself of."

When thinking about their action research, they felt that the experience felt more like "reflecting on [their] teaching." They described the challenge of reconciling their idea of research with the reality of chemical education research.

- "It also makes me feel like I'm not doing research and makes me feel more like I'm just reflecting on my teaching, which is a good practice. I'm not hating on reflecting on my practice. In the context of a research thing, it makes me feel like sometimes I'm not doing research based on how I view what research is."

They concluded by describing their current attitudes toward their action research project.

- "I feel like I'm in a better spot with it."

In terms of program expectations, Taylor "had no idea really what to expect coming in" to the MS program. They again reflected on this MS program versus other master's programs in which their colleagues have participated. They then shared an experience speaking to a colleague whose graduate program approached content differently than the MS program.

- "I don't always feel the same way when I talk to other teachers who are doing their master's program and they're almost bragging about how they didn't have to do much. I felt challenged, which is good, but not so challenged that it was too much. I was having a conversation the other day and [their colleague] was taking biochem, but the professor almost treats it as if you're a student who just got done with their undergrad and is now going into grad meaning that, 'hey, you guys certainly remember the organic chemistry that you would have learned last year?' In other words, more recent in your head.' And he's like, 'I haven't been in organic chem in like 13 years.'"

Taylor reflected that they did not have goals for pedagogical change during the MS program; however, they do enjoy the pedagogical components of the MS program.

- "I felt what I have done and what I continue to do pedagogically that hasn't needed to be a product of the program itself. I felt good about that, but at the same time I like doing the pedagogical stuff when we're doing it."

Taylor then discussed their plan to use activities they developed in Summer 1. They hoped to integrate the lab they developed during their first summer on campus but described the circumstances that led to its exclusion in the school year that followed. This statement is reflective of their KoCO, demonstrating obstacles to executing curricular changes. By improving their KoCO, Taylor experienced improved PCK.

- "I really wanted to do – and I might still do – that Vitamin C extraction from different fruits. A lot of it came back to poor anticipation and timing on my part. In that moment you can see where it's going to fit and then the year happens and by the time you think about it, it's either too late or you think about it early enough but you have other more demanding priorities, so it gets put off, and then it just ends up not making its way in."

When reflecting on changes due to their research, they stated an improvement to their awareness of bonding misconceptions. Although they stated they did not gain KoR, they improved their KoSt by learning about potential misconceptions, which indicated improvements to their PCK.

- "In the summer we were working on the research stuff and so the stuff that I looked into regarding misconceptions with bonding, that for sure played a role in terms of awareness. Nothing from an activity point of view."

In terms of laboratory knowledge, Taylor discussed KoSc that they took away from the research experience to apply to their laboratory instruction. By combining their KoSc and KoT, Taylor demonstrated improved PCK quality. They gave an example related to the "separation of emulsions." They were able to adapt the technique using available equipment.

- "I don't have a rotovap, but we do have these simple distillation kits, and so I know when they have their dichloromethane and their caffeine, we have to get rid of the dichloromethane. We did it in a rotovap, which is nice at SDSU. We don't have that, but we could do a simple distillation set up."

While in the research lab, Taylor described reverting to a student mindset which required more dependence or guidance from an instructor.

- "It's funny how quick you fall into that student mindset of 'should I be doing this? Is this okay?'"

They discussed the lack of spectroscopy in their classroom due to a lack of knowledge. Gaining KoSc expanded Taylor's ability to integrate different instrumentation into their laboratory instruction.

- "It's not like we're going to do NMR anytime soon around here and I've never really had a strong desire to use spec for anything in particular, but that was more so because I didn't know."

Taylor reflected on the logistical challenges they faced while working toward their MS degree, including the challenge of balancing family time, coaching, and the MS program on top of teaching. They stated that these challenges have "taken a big toll on [their] life," but that they ultimately had "a good experience" in the MS program.

- "Because I don't have a problem talking about and defending ultimately what I've been doing because I enjoy talking about that stuff, but it's the logistical pieces. The logistical pieces have been a lot more of a challenge for me since [their child] was born and baseball [coaching] started, so it's taken a big toll on my life this past year to keep up with this, but having the family to support you with it and being understanding and just little things like, 'Okay, you know. Can you put the girls to bed tonight?' That sort of thing. It definitely makes it easier, but at the same time makes it harder in other ways because you feel like you're not as a part of things. But it's part of the game. It's part of being in this program. And so yeah, it's been overall a good experience."

The conversation then transitioned to the current summer session. They described their first couple of weeks in the online portion of CHEM 776. They expressed positive perceptions of the discussions of new teaching ideas in the course. Gaining KoT led to the enhancement of Taylor's PCK.

- "I know we're only two weeks into the lab thing online, but I like being pushed into new ideas and talking about them and considering it from this angle and that angle…[After discussing digital badging] I was like, 'okay. I wouldn't have thought of that otherwise.' I like the ideas that get pushed around in that class."

When asked if Taylor planned to take the demonstrations or waste disposal courses in Summer 1, they stated that they weren't "aware" of these courses. When asked if they planned to take these courses in Summer 2, they shared the following statements:

- "I'll put it like this: if I don't have to, I'm not. I definitely would like to. I want to know more about demos. I definitely want to know more about waste and safety and proper disposal of things. For me it's always been a 'how much is on my plate' thing. I feel like I've been pushing myself for this time that I'm just like, 'look, I'm going to meet the requirements of the program.' By no means does that mean that you're not doing work because I know that I'm doing a lot of work."

Taylor expressed their attempt to realistically limit their workload, which meant they did not plan to take the elective courses. They then reflected on their goal to limit their obligations by "saying no."

- "I'm trying to work on saying no to things because that's important. I say yes too much or take on too much and then you end up doing a bunch of things not well and so I don't feel like I would be giving my full attention that I would want to if I was in classes like those."

Although they did not plan to take these courses, they shared their desire to gain demonstration ideas from their peers. By increasing their KoR, Taylor could improve their overall PCK.

- "I think [the elective courses] are really cool ideas, and I like hearing from the people that have taken them, and then to be honest bumming some of the ideas that they have and that they came up with from the demos class."

Taylor reflected on why they felt the summer was a meaningful component of the MS program. Connecting to the "Interactions" code, they discussed their experience building connections with other MS program participants who they knew they would eventually meet in person, rather than feeling "disconnected" if the MS program were entirely online.

- "I think the first part is more a psychological part and a social part. It's like I'm part of something. It's not just this world that exists online completely disconnected from me. I think even if it's not necessarily while you're there, it's knowing that there's inevitably going to be a time where I'm going to meet these people and talk to these people, and so you by default end up building camaraderie with those people beforehand. Then when you finally meet them, you're like, 'oh, yeah, you're you' so there's almost that feeling of coming togetherness. We're in this together."

They then reflected on the value of conducting laboratory research on campus. The campus research experience allowed for a unique professional development opportunity.

- "The research part, like the lab setting, I just wouldn't get that anywhere else and certainly not at school."

Taylor felt that the campus experience helped them develop professionally during the summer. Being on campus allowed them to develop new perspectives both as a teacher and a learner, especially by participating in the organic lab during Summer 1.

- "It's just good for you as a teacher. I think it's super easy to adopt the mindset of summer – checked out and I'm not coming back – and then it's fall. These two weeks I'm going to go hard on this stuff and do a lot of things that I actually really enjoy doing and being able to do some of the things I wouldn't normally be able to do. It's going to make me better as a teacher, then also better in some ways as a learner because a lot of it was new to me or because it had been X years since I had done that in college. You see things from a different perspective too. I did at least, like the organic lab and you have this equipment and that equipment, and I obviously would have never paid attention to that stuff when I was in school in that moment."

Taylor reflected on their excitement reading journal articles to compile a literature review for their action research project, while acknowledging the need to conclude their search and move toward applying that knowledge. Their action research project enabled Taylor to improve their KoT as a component of their PCK.

- "I was for excited to read what I was reading. I got a lot of ideas and good things that came from that, so I'm going to struggle making sure I don't just constantly find article[s] and I'm actually doing something with it and constructing something.

Summary of Reflection

Taylor shared many reflective thoughts during their seventh check-in interview. The main themes for reflection were:

- Taylor reflected on being “in a better spot” with their action research project progress and discussed how they could make changes to their action research in the future. They shared the intertwining of the chemical education research and reflections on their own teaching practice. This led to improvements to Taylor’s KoT as a component of their PCK.
- Although Taylor did not know what to expect in the MS program, they discussed feeling appropriately challenged as a chemistry teacher ten years removed from their undergraduate studies. They were challenged by the chemistry content and were exposed to new research and pedagogical ideas that they could incorporate into their own teaching, which improved their PCK by increasing their KoSc, KoT, and KoR.
- They reflected on activities and procedures they would like to bring back to their classroom from their first summer research experience, including a Vitamin C extraction, spectroscopy, and separation of emulsions. This improvement to their KoR and KoSc led to improved PCK.
- Taylor again reflected on the challenges they faced during their second year in the MS program, relating mostly to balancing family life, coaching, research, and other MS program responsibilities on top of their teaching.

- Due to their struggles with needing balance, Taylor shared their desire to "work on saying no." Because of this, they did not plan to take the summer elective courses on demonstrations and waste disposal.
- The MS program provided opportunities for laboratory research that Taylor would not be exposed to otherwise. The campus research experience offered a unique professional development opportunity for high school science teachers.
- Taylor reflected on the value of connecting with other MS program participants, especially during the summer campus experience. These interactions supported Taylor's PCK and professional development. They described gaining KoR through these interactions, which led to improved PCK.

Codebook 3

Taylor shared six comments coded as "Feedback." These statements were further analyzed using Codebook 3. These coding frequencies are shown in Table 128 below.

Table 128. Check-in Interview 7 Coding Frequencies – CB3

Code	**Abbreviation**	**Frequency of Responses (*N* = 7)**	**Percentage of Total Responses (%)**
Assignment Feedback	AF	1	14.3
Program Feedback	PF	4	57.1
Logistical Feedback	LF	2	28.6

Assignment Feedback

Taylor shared their enjoyment of the CHEM 773 equilibrium book assignment and request to see the compilation of all participants' contributions.

- "I thought the equilibrium book idea that they did was actually pretty cool. I think they published it. I don't know if I immediately know where it is, where everybody's contribution is together. Not really quite sure. If they haven't, I'd love to see something like that."

Program Feedback

Taylor shared their appreciation for the flexibility of MS program instructors, especially their research advisor.

- "I've really liked and appreciated the flexibility of the professors throughout the whole time. Instructor B has been great as far as being willing to meet, being flexible with things, and also [being] willing to engage with questions. It's not so much them talking at me or 'we'll just do this, this and this.' It's more so two people having a conversation about this thing and that's really nice."

Taylor felt that the summer session was "for sure" a meaningful component of the MS program.

- "I think it's so meaningful that it's a requirement. I think it *is* a requirement. But I like that it's a requirement. I like that it's a recognition that you're getting something out of this. It's hard to quantify. It's just having that experience – the things that you learn there, the relationships or the people that you meet – and I think it's just good for you as a teacher."

Taylor shared what they liked about the MS program in terms of how it approaches chemistry content for teachers who are not recent college graduates.

- “What I like about this [MS program] is that there seems to be an awareness that we're not recently college grads. We're teachers, but, at the same time, that doesn't mean you dumb it down. It just means that you have to be more intentional about how we're approaching certain things and that it’s not fresh in everybody's memory. We’re all sorts of ages in the program and so I really liked that. It did feel very content heavy, which I personally liked.”

Logistical Feedback

Related to MS program logistics, Taylor expressed their desire to have instant formative feedback on homework problems through an online system. The teacher-initiated study groups allowed for immediate feedback, but they shared their desire for this to be embedded in MS program courses.

- “I know that SDSU would have the capability to do [have] some kind of electronic system that is formative in nature where it can assign homework problems and students can get feedback. It's nice to get your feedback, for example, when we turn in Instructor A’s stuff, but that happens presumably at the end of the homework session. It would be nice to know ‘am I going about this in the right way?’ a little bit sooner. That's also why I go to those study sessions, so that kind of works out.”

They then elaborated on the value of having immediate feedback through an online homework system. In addition to have immediate feedback, they hoped to have more “check-in” homework problems to support the clarity of their content understanding.

- “it’s the immediacy of knowing whether I'm doing it right or wrong, but then also there's a learning component to it as well. Whatever that software was in [CHEM 775], it was nice…I think at a minimum is some sort of immediacy…The homework right now could still very much be a thing, but it would almost be like ‘I could ask these five questions related to this lesson and this lesson.’ You're not going to be graded on them, but that would give me more clarity going into the actual homework that we're writing down and submitting online. Just to have some kind of check-in.”

Codebook 4

Codebook 4 was used to demonstrate the motivations behind Taylor’s comments. These coding frequencies are shown in Table 129 below.

Table 129. Check-in Interview 7 Coding Frequencies – CB4

Code	**Abbreviation**	**Frequency of Responses (*N* = 49)**	**Percentage of Total Responses (%)**
Learning-focused	L-f	30	61.2
Student-focused	S-f	2	4.1
Teaching-focused	T-f	17	34.7

Most of Taylor’s comments were motivated by the learning that took place in the MS program (61.2%), with over a third of their comments relating to teaching-focused motivations (34.7%). They shared two comments motivated by implications for student learning (4.1%). An example of each coded response is given below.

- "I actually learned quite a bit of new things [and] applications of things, especially in the context of equilibrium." (L-f)
- "What I have done and what I continue to do pedagogically and developing, that hasn't needed to be a product of the program itself." (T-f)
- "I have to remind myself that my students aren't grad students, so we'll talk about titrating a weak acid with a strong base. And it's like, 'Okay, maybe they don't need to know the Henderson-Hasselbalch equation.' It's not really necessary for what we're going to do and it's more of an issue at the Gen Chem level. But I think it's allowed me to push my Honors chem to another level to make it a little bit more rigorous." (S-f)

Summary of Check-in Interview 7

Taylor reflected on their experience in the MS program during Semester 4 and shared their hopes for their second summer session, which was their final term in the MS program. Taylor primarily shared comments motivated by their own learning (61.2%), with approximately one-third of their comments relating to their teaching (34.7%). Two statements were motivated by their students' learning. The main themes from Check-in Interview 7 were:

- Taylor shared feelings of anxiety related to completing the MS degree. Additionally, they discussed the "big toll" the MS program has had on their life, in combination with teaching, coaching, and family life. They described the challenge of finding balance between their various obligations, which led to decreased research productivity. Although they shared the emotional struggles they faced, they described feeling “in a better spot” in terms of their action research and their standing in the MS program as a whole. In order to find more balance, Taylor expressed their desire to “work on saying no.”

- Gaining chemistry content knowledge and laboratory knowledge through the MS program improved Taylor’s teaching confidence and enabled them to implement new KoSc, KoCO, and KoR in their classroom, demonstrating a positive impact on their PCK. Taylor felt adequately challenged in the MS program in regard to chemistry content, which allowed them to bring complex chemistry topics into their classroom.
- Their Summer 1 research experience exposed Taylor to new laboratory techniques and equipment that had a direct impact on their acquisition of new laboratory resources in their department. With this new equipment, Taylor hoped to carry out organic chemistry procedures with their students. By improving their KoSc and combining it with their KoT, Taylor demonstrated enhanced PCK as well as increased PCK quality.
- Taylor’s remaining goals for the MS program involved exposure to new research ideas in an SDSU lab, making progress on their action research paper prior to coming to campus, and defending their action research project in July 2023.
- The summer campus experience allowed for meaningful in-person connections with other MS program participants and improved argumentation during course discussions. Taylor also gained new KoR through interactions with peers in the MS program.

- Taylor shared feedback related to a CHEM 773 assignment, the flexibility of MS program instructors, the value of the summer campus experience, the MS program's accommodation for teachers who are not recent college graduates, and their desire for an online homework system that would provide immediate feedback in the MS content courses.

Summer Journals

Participants involved in the summer session were invited to complete three guided summer journals surrounding their on-campus experience at SDSU. Each of the summer journals was coded using Codebooks 1 and 3, when applicable.

Summer Journal #1

The first journal was prompted prior to teachers arriving on campus and focused on their goals for the experience, both as a teacher and as a scientist, and what they anticipate the experience to be like.

Codebook 1

Coding frequencies for Codebook 1 can be found in Table 130.

Table 130. Summer Journal #1 Coding Frequencies for Summer 2 – CB1

Code	**Abbreviation**	**Frequency of Responses (N = 8)**	**Percentage of Total Responses (%)**
Attitudes	A-p	2	25
Knowledge	K-p	1	12.5
Goals	G	5	62.5

Reflection	R	1	12.5

Attitudes (A-p) and Knowledge (K-p)

Taylor shared positive attitudes toward coming to campus in light of their first summer experience.

- "My experiences from the first summer have made me even more excited to attend this summer. Simply having a better idea of what to expect has made me feel more comfortable."

Taylor also felt positive about their expected learning outcomes due to the knowledge they gained during their first summer on campus.

- "Additionally, I felt like I learned so many things last summer that it's made me really look forward to all the new things I'll learn this summer."

Goals (G)

Taylor shared three goals for their time on campus related to their action research project and the laboratory research component of CHEM 776. These goals would improve Taylor's PCK through increased KoSc.

- "Be in a comfortable place with respect to how I feel about my research paper."
- "Gain clarity on how to properly analyze the results from my action research."
- "Learn as much as I can when conducting lab research with the ice core group."

Then Taylor shared their goals for the two-week experience as a teacher and as a scientist. These goals related to lab development and exposure to lab techniques and instrumentation. These goals related to potential improvements to Taylor's KoSc, KoT, and KoR.

- “As a teacher, I hope to develop at least one lab that I'm excited to implement in the classroom next year.”
- “As a scientist, I hope to increase my exposure to various lab techniques and better understand lab equipment that I don't normally have access to.”

Reflection (R)

Taylor reflected on the value of the campus research experience, declaring its impact on their professional development.

- “I think this 2-week lab research requirement is a wonderful aspect of the program largely because I think it helps to make me a better overall science educator.”

Codebook 4

Codebook 4 then allowed me to break down Taylor’s statements by source of motivation. Each comment was assessed to determine the focus of the comment, either focused on the participant’s learning, their students’ learning, or the participant’s teaching. Coding frequencies are displayed in Table 131.

Table 131. Summer Journal #1 Coding Frequencies for Summer 2 – CB4

Code	**Abbreviation**	**Frequency of Responses (*N* = 5)**	**Percentage of Total Responses (%)**
Learning-focused	L-f	3	60
Teaching-focused	T-f	2	40

Taylor's comments in their first journal entry were motivated by their own learning (60%) and teaching (40%). They did not express any student-focused motivations in Summer Journal #1. An example of each coded statement is given below.

- "As a scientist, I hope to increase my exposure to various lab techniques and better understand lab equipment that I don't normally have access to." (L-f)
- "As a teacher, I hope to develop at least one lab that I'm excited to implement in the classroom next year." (T-f)

Summary of Summer Journal #1

In their first journal entry, Taylor's comments were motivated by the learning they hoped would take place while on campus (60%), with implications for improved teaching (40%). The main themes from Summer Journal #1 were:

- Taylor shared goals for making progress on their action research project, gaining experience with new laboratory techniques, and developing "at least one" lab activity for use in their classroom. These improvements to their KoSc and KoT would improve Taylor's overall PCK.
- Since this was Taylor's second summer on campus, they expressed the value of the campus research component of the MS program. They shared positive attitudes toward the summer experience due to past learning outcomes and impacts on their teaching.

Summer Journal #2

The second summer journal was prompted after the teachers had spent one full week on campus. The journal asked teachers to reflect on their experience in their assigned research lab, as well as the summer courses.

Codebook 4

Coding frequencies are shown in Table 132.

Table 132. Summer Journal #2 Coding Frequencies for Summer 2 – CB1

Code	**Abbreviation**	**Frequency of Responses (*N* = 14)**	**Percentage of Total Responses (%)**
Attitudes	A-c	3	21.4
Knowledge	K-c	1	7.1
Teaching	T	3	21.4
Interaction	I	1	7.1
Experience	E	2	14.3
Reflection	R	4	28.6

Attitudes (A-c)

Taylor shared feeling overwhelmed by the quantity of new information; however, their desire to learn overshadowed this feeling. This relates to Taylor's gain of KoSc as a component of their PCK.

- “At times, all of the new information feels a bit overwhelming, but I've found myself wanted to really learn about the subtle details of so many things that the feeling of being overwhelmed dissipates.”

The research experience led Taylor to gain a greater appreciation for the time and effort it takes to perform quality research.

- “As a scientist, it's really made me appreciate the lengths scientists will go to generate high quality data…The amount of time and effort that goes into careful sample preparation is something that I respect and can appreciate given the value the data will eventually provide.”

They also described feeling more passionate for “doing science” as a result of the research experience.

- “It's so refreshing to…do things in the research lab that rekindle that passion I have for doing science.”

<u>Summary of Attitudes (A-c)</u>

Despite feeling initially overwhelmed by the overload of new information, Taylor gained a greater appreciation for the research process and rekindled their passion for “doing science.”

<u>Knowledge (K-c)</u>

CHEM 776 allowed them to gain new ideas for chemistry lab activities related to environmental topics. By gaining KoSc and KoR, Taylor further developed their PCK during the campus research experience.

- “The lab development course has really helped me with gathering lab ideas that emphasize environmental ideas within the context of chemistry.”

Teaching (T)

Taylor described their desire to bring aspects of their campus experience back to their teaching. Their time in the research lab equipped them with new examples and learning opportunities to share with their students. By combining their KoSc, KoT, and KoR, Taylor demonstrated improvements to their PCK quality.

- "As a teacher, there have been several moments where I felt that a recent experience would be a great learning opportunity for my students."
- "Even in the numerous conversations had with [research professor] and the other researchers, I've stumbled upon so many little things that can serve as practical examples to share with my students regarding content and science practices."

Taylor also wanted to bring environmental chemistry labs into their teaching and the CHEM 776 discussions provided them with new ideas. By increasing their KoT and KoR, Taylor experienced improvements to the quality of their overall PCK.

- "Incorporating environmental chemistry applications is something that I wanted to improve upon going into next year and nearly every single lab we've discussed and then attempted has a high chance of making its way into my classroom next year."

Summary of Teaching (T)

Taylor discussed their desire to bring back learning opportunities to share with their students related to their SDSU research experience, as well as new environmental chemistry lab activities. By improving their KoT and KoR, Taylor demonstrated improved PCK quality.

Interaction (I)

Taylor discussed the value of sharing ideas with other MS program participants. These interactions allowed for the exchange of KoR as a component of PCK.

- “It's so refreshing to share ideas with other chemistry teachers.”

Experience (E)

Taylor shared experiences they had during their first week in an SDSU research lab. They described differences between their first and second lab experiences in the MS program.

- “It's pretty fascinating…Since I had already worked in a research lab last year, my expectations really haven't been much different than what I expected. The content and instrumentation are definitely different than what I expected but that's more because I had little to no baseline for comparison.”

Taylor related an experience shared by one of the GTAs in their lab that they were inspired to share with their students.

- “Just the other day, one of the researchers informed us that the instrumentation had stopped working at some point overnight. So, they thought it might be useful to inform us of their approach to troubleshooting the problem since they needed to collect the data and couldn't just call someone quickly to fix it. After attempting to diagnose and remedy the problem in several different ways, they were eventually able to fix it. Then, they told me that they went back to their lab notebook and continued to describe the approach they took to troubleshooting by recording it all in their lab notebook.”

Summary of Experience (E)

Taylor related two aspects of their campus experience, including their exposure to new instrumentation and content compared to their first summer, as well as relating a GTA's experience troubleshooting an instrumentation issue.

Reflection (R)

Taylor shared comments in their second journal entry that reflected on different aspects of the research process. Taylor first discussed the necessity of paying attention to detail when conducting laboratory research.

- "In the analytical research area, so much of generating quality data is about paying careful attention and accounting for the little things"

They also reflected on the collaborative nature of laboratory research based on what they observed in their assigned lab. This collaboration supported Taylor's PCK and professional development.

- The research experience "has also made me recognize the natural collaborative efforts that are made in the pursuit of advancing our collective knowledge. Hearing about the different ice core research labs that analyze the same set of cores or share sample preparation methods to make the sample preparation process more efficient sheds light on how science is so closely tied with collaboration between individuals and groups."

This experience also gave them experiences to relate to their students regarding the importance of maintaining a detailed lab notebook.

- "As a teacher, I thought this was a great opportunity for learning because so many of my students want to simply erase work in their lab notebook if something didn't turn out correctly. I always try to tell them that scientists record everything, even the mistakes, by drawing a line through that information and continuing to write things down below. To see a scientist actually doing this in practice was a subtle moment that I know I will share with my students to make a point about how we record things in our lab notebooks."

Finally, Taylor reflected on having a second meaningful campus experience.

- "After having such a meaningful experience last year, it's good to know that one week into my second summer term here, it's still proving to be meaningful."

Summary of Reflection (R)

Taylor reflected on multiple experiences they had in their assigned research lab that they planned to bring back to their students, including the importance of paying attention to detail, the collaborative nature of laboratory research, and the importance of maintaining a detailed lab notebook.

Codebook 4

Codebook 4 then allowed me to break down Taylor's statements by source of motivation. Each comment was assessed to determine the focus of the comment, either focused on the participant's learning, their students' learning, or the participant's teaching. Coding frequencies are displayed in Table 133.

Table 133. Summer Journal #2 Coding Frequencies for Summer 2 – CB4

Code	**Abbreviation**	**Frequency of Responses (*N* = 9)**	**Percentage of Total Responses (%)**
Learning-focused	L-f	6	66.7
Student-focused	S-f	2	22.2
Teaching-focused	T-f	1	11.1

In their second journal entry, Taylor shared comments motivated by their learning (66.7%), their students' learning (22.2%), and their teaching (11.1%). An example of each coded response is given below.

- "At times, all of the new information feels a bit overwhelming, but I've found myself wanted to really learn about the subtle details of so many things that the feeling of being overwhelmed dissipates." (L-f)
- "As a teacher, there have been several moments where I felt that a recent experience would be a great learning opportunity for my students." (S-f)
- "Incorporating environmental chemistry applications is something that I wanted to improve upon going into next year and nearly every single lab we've discussed and then attempted has a high chance of making its way into my classroom next year." (T-f)

Summary of Summer Journal #2

The second journal entry described Taylor's first week on campus. They shared statements motivated by their own learning and teaching, as well as their students' learning. The main themes for Summer Journal #2 were:

- Taylor gained new lab ideas and examples about the research process to bring back to their students, as well as a rekindled passion for applying their scientific knowledge. By combining their KoSc and KoT, Taylor demonstrated improved PCK quality.
- Taylor planned to apply their experience in the CHEM 776 course, including their time in a research lab, to their teaching, demonstrating the MS program's impact on teachers' professional development. By combining their KoSc and KoT, Taylor demonstrated improvements to the quality of their overall PCK.

Summer Journal #3

The third and final journal entry was prompted after participants had completed their two weeks on the SDSU campus. The prompting questions asked the teachers to reflect on what they have gained through their experience, such as professional development, networking opportunities, and other takeaways. Teachers were also asked to share their thoughts on the summer session, including if their expectations were met, how the on-campus experience went overall, and any other final thoughts on the two-week session.

Codebook 1

Coding frequencies from Codebook 1 are shown in Table 134.

Table 134. Summer Journal #3 Coding Frequencies for Summer 2 – CB1

Code	**Abbreviation**	**Frequency of Responses (*N* = 23)**	**Percentage of Total Responses (%)**
Attitudes	A-c	4	17.4
Knowledge	K-c	4	17.4
Skill	S-c	1	4.3
Goals	G	1	4.3
Experience	E	2	8.7
Teaching	T	2	8.7
Feedback	F	2	8.7
Interaction	I	5	21.7
Reflection	R	2	8.7

Attitudes (A-c)

Taylor described an increase in their comfort level with the campus research experience compared to their first summer.

- “My general level of comfort the second time around made the whole experience really valuable.”

They also described their confidence with being able to contact MS program instructions, fellow teachers, or SDSU faculty if they have any questions in the future. These statements are discussed below in the “Interaction” section.

Knowledge (K-c)

Taylor described knowledge gains from their two-week campus experience, specifically knowledge of lab techniques and other scientific research practices. By gaining KoSc, Taylor improved their overall PCK.

- "I've become more knowledgeable of lab techniques I hadn't experienced before…such as ion chromatography and mass spec."
- "As a scientist, the many discussions we had with [their research professor] regarding their work really shed light on a wide variety of scientific practices that gave me a deeper insight into carrying out research in a methodical way."
- "I gained quite a bit of knowledge" during the campus research experience.

Skill (S-c)

In terms of skill, Taylor discussed improvements to their educational research skill in terms of interacting with the literature. This interaction with the literature allowed for the improvement of Taylor's KoT and KoR as components of their overall PCK.

- "I feel like I've become better at access, summarizing, and potentially implementing lab ideas found in journals like J Chem Ed."

Goals (G)

When reflecting on their goals for the summer campus experience, they discussed making progress toward their goals for their action research project.

- "One of my biggest goals was to make large gains on my action research paper…The progress I made on the paper while there helped me significantly."

Experience (E)

Taylor shared details of their experiences on campus. They first discussed progress they made on their action research project.

- "During the summer experience, I spent quite a bit of time on [their action research paper] and by the time I left, I was in a good position to finish up whatever remained when I got back home."

They then described their experience in an SDSU research lab.

- They "had fun actually cutting and analyzing trace impurities in ice cores."

Teaching (T)

After participating in CHEM 776 on campus, Taylor felt more comfortable incorporating environmental topics into their instruction. By combining their KoT and KoSc, Taylor demonstrated improvements to their PCK quality.

- "I feel a lot more comfortable incorporating environmental related topics into my chem class as a result of being in the Ice Core Research group and the lab ideas chosen by Instructor A for use to review and implement."
- "As a teacher, [the summer research experience] helped me think of all kinds of new ideas about how to implement ice core chemistry into my curriculum and make connections to a few environmental related topics."

Feedback (F)

Taylor shared two comments coded as feedback. These statements were further analyzed using Codebook 3, which will be shared in the section below.

<u>Interaction (I)</u>

Taylor reflected on new relationships they formed on campus with fellow MS program participants, their research professor and GTAs, and MS program instructors. Connecting to their A-c, they described feeling confident in being able to contact colleagues and mentors from the MS program in the future. They also revealed their desire to collaborate or continue making changes to their teaching after completing their MS degree. These interactions supported Taylor's PCK and professional development.

- "Meeting new teachers in person has resulting in some new connections to be made that I feel confident I could reach out and collaborate with them."
- "The time spent with [research professor] and their research team made me feel confident I could connect with them in the future if I ever had a question or was looking to find ways to incorporate ice core chemistry into my own classroom."
- "The relationships developed with both Instructor B and Instructor A have given me confidence that I could always reach out to them with questions and discuss ideas."

Taylor discussed forming a professional network with other MS program participants. This indicated that other MS program participants supported Taylor's PCK and professional development.

- "I've been able to grow my circle of teachers that I can collaborate with on ideas."

They also compared the number of participants to their previous experience, sharing that the group of teachers felt like a community.

- "There were a lot more teachers this summer than last. This was nice because it had more of a small community type feel to it I suppose."

Reflection (R)

Taylor reflected on the value of observing the research process and taking back practical lab experience to their students. This combination of their KoSc and KoT demonstrated improvements to Taylor's PCK quality.

- "It was also really useful to see how research is carried out in a practical sense, such as how the grad students utilized their lab notebooks, so that I can bring back some of these observations to my students when we are carrying out labs."

Taylor compared their two summer campus experiences, reflecting that they were better prepared for their second summer in terms of time management and meeting their goals.

- "Since this was my second summer, the biggest difference for me was just my general level of preparedness. I knew how important it was that I gained a lot of ground on my research paper, so it basically forced me to manage my time wisely and complete other tasks in such a way that gave me adequate time to work on my paper."

Codebook 3

Taylor shared two comments coded as "Feedback." These statements were further analyzed using Codebook 3. These coding frequencies are shown in Table 135 below.

Table 135. Summer Journal #3 Coding Frequencies for Summer 2 – CB3

Code	**Abbreviation**	**Frequency of Responses (*N* = 2)**	**Percentage of Total Responses (%)**
Program Feedback	PF	2	100

Program Feedback

When reflecting on their two-week campus experience, Taylor shared feedback related to the research experience. They first expressed their desire to have more daily responsibilities in their own research lab.

- "It would have been nice if we had more things to do and actually carry out on a daily basis [in the research lab] but the overall experience was good."

They then shared general feedback for professors hosting teachers in their labs, particularly regarding the degree to which teachers were involved in the daily research procedures.

- "I think the overall two weeks on campus idea is great. The only thing I would tweak is the general expectations of professors to ensure that teachers have something to work on daily while in their research labs. If certain things related to their research can't be carried out by teachers, that's understandable. However, something else needs to be considered then and it would just be nice to see a bit more preparation from those who are hosting teachers in their labs. Though I had two really nice experiences, I know others who felt like they were just sort of dropped into a lab research group and little to no thought had been given by the professor as to what those teachers would do on a daily basis."

Codebook 4

Codebook 4 then allowed me to break down Taylor's statements by source of motivation. Each comment was assessed to determine the focus of the comment, either

focused on the participant's learning, their students' learning, or the participant's teaching. Coding frequencies are displayed in Table 136.

Table 136. Summer Journal #3 Coding Frequencies for Summer 2 – CB4

Code	**Abbreviation**	**Frequency of Responses (*N* = 11)**	**Percentage of Total Responses (%)**
Learning-focused	L-f	8	72.7
Student-focused	S-f	1	9.1
Teaching-focused	T-f	2	18.2

Taylor's statements were primarily motivated by their own learning gains (72.7%), but they also included teaching-focused (18.2%) and student-focused (9.1%) motivations. An example of each code is given below.

- "I've become more knowledgeable of lab techniques I hadn't experienced before." (L-f)
- "As a teacher, [the summer research experience] helped me think of all kinds of new ideas about how to implement ice core chemistry into my curriculum and make connections to a few environmental related topics." (T-f)
- "It was also really useful to see how research is carried out in a practical sense, such as how the grad students utilized their lab notebooks, so that I can bring back some of these observations to my students when we are carrying out labs." (S-f)

Summary of Summer Journal #3

In their final journal entry, Taylor reflected on their two-week summer campus experience. Most of their comments related to their own learning gains (72.7%), but they also shared statements motivated by their teaching (18.2%) and their students (9.1%). The main themes for Summer Journal #3 were:

- Upon comparing their first and second summers on campus, Taylor felt that they were more comfortable and better prepared for their second campus experience.
- Through participating in an SDSU research lab and CHEM 776 discussions, Taylor gained knowledge of lab techniques, educational research, and research practices. By increasing their KoSc, Taylor improved their overall PCK.
- Taylor met their goal for making progress on their action research paper, a requirement for completing the MS program. They were able to achieve this goal using improved time management skills.
- Taylor planned to bring their experiences into their instruction by incorporating environmental topics and research practices into their chemistry curriculum. By combining their KoSc, KoCO, and KoT, Taylor demonstrated improved PCK quality.
- Taylor made connections with other MS program participants, SDSU faculty, and GTAs and felt confident in their ability to use these connections in the future for further collaboration and professional development. These interactions also supported Taylor's PCK development.

- Taylor gave feedback requesting hosting professors to offer more daily responsibilities for teachers in the SDSU research labs.

Post-Campus Summer Survey

After the conclusion of the two-week on-campus session, participants were invited to complete a survey about their time on campus. Teachers discussed the most and least beneficial aspects of the two-week experience, how their view of the research process has or has not been impacted by their time in SDSU research labs, and if they plan to change the laboratory work they do with their students as a result of their experience in CHEM 776. Teachers also provided feedback for the summer courses, which will be discussed in Chapter 6.

Codebook 1

Coding frequencies for Codebook 1 are presented in Table 137.

Table 137. Post-Campus Summer Survey Coding Frequencies for Summer 2 – CB1

Code	**Abbreviation**	**Frequency of Responses (N = 13)**	**Percentage of Total Responses (%)**
Attitudes	A-c	2	15.4
Knowledge	K-c	1	7.7
Teaching	T	3	23.1
Feedback	F	3	23.1
Experience	E	1	7.7
Reflection	R	3	23.1

Attitudes (A-c)

Taylor stated that their experience in CHEM 776 “helped [them] feel more comfortable with more things in the lab setting.” They also described gaining “confidence in how the lab [activity] functions” resulting from performing labs in the CHEM 776 course.

Knowledge (K-c)

Through their experience in an SDSU research lab, Taylor gained knowledge in the utility of different chemistry instrumentation. By improving their KoSc, Taylor further developed their PCK.

- “I feel like I'm more knowledgeable of what lab instruments could be used to achieve an outcome.”

Teaching (T)

Taylor described the impact of the campus experience on their teaching. They first described gaining KoR that could be used in their lab instruction. By combining their KoT and KoR, Taylor demonstrated improved PCK quality.

- “Being able to come back home with lab ideas that I've actually performed makes it more likely that I will find a way to incorporate them into my own curriculum.”

Taylor stated that they have used labs or activities developed in a previous summer on campus. They shared a teaching experience of implementing a caffeine extraction lab that they learned about in CHEM 776. They emphasized the impact that the campus lab experience had on their teaching. By applying their KoSc and KoR to their KoT, Taylor demonstrated improvements to the quality of their overall PCK.

- "Last summer, I was able to perform a caffeine extraction using a few different organic solvents. I really dove into this because I had hoped to turn it into a lab for my honors chem class. This past year, that's exactly what I did. My Honors chem class performed a caffeine extraction lab that allowed us to explore new lab techniques and do something that was a bit more advanced. I would've never done this lab had I not had the experience at SDSU the previous summer."

They described the utility of testing these labs on campus, relating that gaining confidence in the lab's functionality influenced their decision to implement it into their curriculum. By combining their KoT and KoR, Taylor demonstrated improvements to their PCK quality.

- "It really helped to have already had experience performing the lab while at SDSU…Being able to have confidence in how the lab functions in reality makes it more likely that I was going to integrate it in my class."

Summary of Teaching (T)

Taylor stated that the CHEM 776 course has actively impacted their teaching. Being able to perform labs on campus increased the likelihood that they would bring the activity into their instruction. Thus, the MS program has enabled a teacher to bring new labs into their classroom that they may not have included otherwise. By combining their KoCO, KoT, and KoR, Taylor demonstrated improvements to their PCK quality.

Feedback (F)

Taylor shared three comments coded as feedback. These statements were further analyzed using Codebook 3, which will be shared in the section below.

Experience (E)

Taylor described their experience in the CHEM 776, detailing the impact of engaging with a lab both in theory and in practice. The course also gave Taylor new ideas for environmental chemistry lab activities, which increased their KoR as a component of their overall PCK.

- "I really like the idea of discussing the underlying concepts and theory behind a proposed lab in the morning and then actually getting the opportunity to perform the lab later that same day. Several of the labs we did in the afternoon tied nicely into some environmental chem ideas and that was an area in which I was lacking quality lab ideas."

Reflection (R)

Taylor reflected on the impact of the summer campus experience, focusing on the discussion of lab activities in CHEM 776 and the laboratory research experience. They stated that gaining resources for their classroom, including through their own lab development, was the most beneficial part of the two-week experience. This improvement to their KoR demonstrated improvements to their overall PCK.

- "As a teacher, I'd say the most beneficial part was lab development and discussion of various labs."

They reflected that most ideas "stay as ideas," emphasizing that performing labs on campus enabled them to actively implement new ideas into their teaching. This exercise combined their KoR and KoT, which enhanced the quality of their PCK.

- “Sometimes teachers come back from conferences or professional development with ideas they intend to implement. However, these ideas tend to follow a habit of staying as ideas.”

CHEM 776 also allowed Taylor to engage with new materials and resources related to the lab. By improving their KoR, Taylor improved their overall PCK.

- “It's helped encourage me to work with chemicals I may not have otherwise considered and has allowed for new lab experiences to be explored.”

Codebook 3

Taylor shared three comments coded as “Feedback.” These statements were further analyzed using Codebook 3. These coding frequencies are shown in Table 138 below.

Table 138. Post-Campus Summer Survey Coding Frequencies for Summer 2 – CB3

Code	**Abbreviation**	**Frequency of Responses (N = 3)**	**Percentage of Total Responses (%)**
Assignment Feedback	AF	1	33.3
Program Feedback	PF	2	66.7

Assignment Feedback

In terms of the least beneficial aspect of the CHEM 776 course, Taylor shared their thoughts on the summary papers on selected journal articles.

- "I'd probably say [the least beneficial part of the two-week experience was] the paper reviews. I think there is value in these, but I much preferred a more in-depth class discussion about these papers instead of it being so individual."

Program Feedback

Taylor also shared feedback on the research experience. They offered a suggestion for professors to allow teachers to perform an upper-level lab and share feedback on the lab itself.

- "I might consider giving professors the option to have teachers in their lab perform and potentially contribute to an upper-level lab performed in that professor's content area. This would expose teacher to potentially new lab techniques and could allow for collaboration in developing or tweaking a lab."

When reflecting on the overall experience, Taylor stated that the two-week campus experience must not be changed about the CHEM 776 course. They expressed the value of the summer component in supporting teachers' development.

- "2 weeks spent at SDSU. Being a graduate program, it really allows teachers to have the experience of diving headfirst into their craft. The connections, knowledge, and skills developed within those two weeks all contribute to becoming a better teacher."

Codebook 4

Codebook 4 then allowed me to break down Taylor's statements by source of motivation. Each comment was assessed to determine the focus of the comment, either focused on the participant's learning, their students' learning, or the participant's teaching. Coding frequencies are displayed in Table 139.

Table 139. Post-Campus Summer Survey Coding Frequencies for Summer 2 – CB4

Code	**Abbreviation**	**Frequency of Responses (*N* = 12)**	**Percentage of Total Responses (%)**
Learning-focused	L-f	8	66.7
Teaching-focused	T-f	4	33.3

Taylor's responses to the post-campus summer survey primarily focused on their own learning that took place on campus (66.7%), but the other third of their comments were motivated by impacts to their teaching. An example for each code is given below:

- "I feel like I'm more knowledgeable of what lab instruments could be used to achieve an outcome." (L-f)
- "Being able to come back home with lab ideas that I've actually performed makes it more likely that I will find a way to incorporate them into my own curriculum." (T-f)

Summary of Post-Campus Summer Survey

Through the post-campus summer survey, Taylor reflected on the overall impact of the summer experience, especially related to their teaching. Taylor's responses were mostly motivated by their own learning (66.7%), but they also described how they plan to apply new knowledge and skills to their teaching (33.3%). The main themes from the post-campus summer survey were:

- Taylor stated that performing labs in the CHEM 776 course increased their likelihood of implementing these ideas in their classroom, especially those related to environmental chemistry. The summer campus experience increased Taylor's KoR as a component of their PCK and impacted their future teaching. By combining their KoT and KoR, Taylor displayed improvements to their PCK quality.
- Taylor brought lab ideas from their first summer into their teaching, evidencing the impact of the CHEM 776 course on their teaching. By combining their KoSc and KoT, Taylor demonstrated improved PCK quality.
- Performing labs and participating in the SDSU research labs enabled Taylor to gain more knowledge of chemistry instrumentation (KoSc), which led to improved PCK.
- Taylor provided feedback for CHEM 776, ultimately emphasizing the value of the two-week campus experience for teachers' development of "connections, knowledge, and skills."

ASCI (pre/post)

Taylor completed both the pre- and post-test of the ASCI. Pre/post data are displayed in Table 140. According to Bauer, the percentage scale indicates the level of the given category that a participant has with respect to Chemistry Laboratory Research, in our case.[64] The categories of attitudes in the inventory include emotional satisfaction, anxiety, intellectual accessibility, interest & utility, and fear.[64] Bauer indicates that a higher score or percentage indicates a higher degree of the attitude; for example, a higher score for anxiety indicates more anxiety and a higher score for emotional satisfaction indicates higher emotional satisfaction.[64]

Table 140. Narrative ASCI Pre/Post Data with Respect to Chemistry Laboratory Research

	Emotional Satisfaction (%)	Anxiety (%)	Intellectual Accessibility (%)	Interest & Utility (%)	Fear (%)
Pre	92	33	43	97	0
Post	79	30	47	93	17

Taking these clarifications into account, we would hope to see an increase in emotional satisfaction, intellectual accessibility, and interest & utility; conversely, we would hope to see a decrease in the teachers' anxiety and fear surrounding chemistry laboratory research.

After the 2-week research experience, Taylor's data indicate a 4% increase in intellectual accessibility and a 13% decrease in their emotional satisfaction toward chemistry laboratory research. Taylor experienced 3% less anxiety after the two-week experience. Taylor experienced a 4% negative shift toward lower interest and utility. The data for fear indicates that Taylor became 17% more fearful of chemistry laboratory research after the summer experience.

End-of-Summer Survey

The end-of-summer survey follows the same format as the other end-of-semester surveys and focuses on what knowledge and skills teachers gained from these courses, along with feedback that participants have shared. The end-of-summer survey was analyzed using Codebooks 1, 3, and 4.

Codebook 1

Coding frequencies for Codebook 1 can be found in Table 141 below.

Table 141. End-of-Summer Survey Coding Frequencies for Summer 2 – CB1

Code	**Abbreviation**	**Frequency of Responses (*N* = 19)**	**Percentage of Total Responses (%)**
Attitudes	A-c	1	5.3
Knowledge	K-c	2	10.5
Skill	S-c	3	15.8
Teaching	T	3	15.8
Feedback	F	5	26.3
Interaction	I	1	5.3
Reflection	R	4	21.1

Attitudes (A-c)

Taylor stated that the CHEM 788 course was worth the money because it gave them the confidence to perform action research in their own classroom.

- "788 - The culminating research project gave me the confidence to perform research in my own classroom if I want to."

Knowledge (K-c)

Taylor identified research knowledge gains as a benefit of the CHEM 788 course. By gaining new KoT, Taylor enhanced their overall PCK.

- "788 – I gained so much knowledge by simply doing the literature review."

Taylor also gained chemistry content knowledge through their experience in an SDSU research lab. By gaining KoSc, Taylor improved their overall PCK.

- "Though I was really exposed to much content during the summer, I actually learned a great deal about environmental-related chemistry throughout my duration in the ice core research lab."

Skill (S-c)

Taylor described gaining new lab skills as a benefit of the CHEM 776 course, which they hoped to apply to their own laboratory instruction. By combining their KoSc and KoT, Taylor demonstrated improvements to their overall PCK.

- "776 – Being introduced to new lab techniques is a skill set that can be transferred to my own lab experiences in the classroom."

Taylor stated that the CHEM 788 course had good value for money due to the research skills they gained. This course supported their PCK development through improved KoT.

- "788 – it really helped me with how to navigate the sea of information within chem ed research in order to find what I'm looking for."

Related to their own teaching effectiveness, they felt that the CHEM 776 course equipped them with improved pedagogical skill in terms of laboratory development. By combining their KoT and KoR, Taylor experienced improved PCK quality.

- "I feel like I have a stronger ability to develop and execute all kinds of new lab experiences with my students that I may not have ever considered in the past."

Teaching (T)

When reflecting on the benefit of the CHEM 776 course, Taylor described the value of learning about new lab ideas they could potentially bring into their teaching. By applying their KoR to their KoT, Taylor displayed improved PCK quality.

- "776 – Gaining exposure to so many lab ideas that I could potentially implement in my class was very valuable."

Feedback (F)

Taylor shared five comments coded as feedback. These statements were further analyzed using Codebook 3, which will be shared in the section below.

Interaction (I)

In terms of interactions, Taylor discussed forming new connections with fellow MS program participants.

- "I've gained several new connections with other teachers that I value."

Reflection (R)

The action research project was beneficial because it allowed Taylor to reflect on their teaching practice.

- "788 – The research I did has helped me reflect on my own teaching practices and develop new approaches to be more effective."

They also reflected on the value for money of the CHEM 776 course. They described the course being financially “worth it” due to their exposure to new resources and ideas, demonstrating improvements to their KoR as a component of their PCK.

- “776 – The access to resources and new lab ideas that I wouldn't have otherwise come across has a lot of value and I felt like the materials I developed and learned about will have a good return on investment.”

Taylor stated that “the exposure to lab ideas that directly relate to environmental chemistry” exceeded their expectations. This improvement to their KoR enhanced their overall PCK.

Finally, they reflected on their two summer campus experiences during the MS program. Taylor felt that the opportunity to be in two different research labs positively impacted their future lab instruction. This combination of their KoSc and KoT indicated improved PCK quality resulting from their two summer sessions in SDSU research labs.

- “Being given several opportunities to work on different labs and in different settings has expanded the potential for what I feel comfortable pursuing in the lab with my own students.”

Summary of Reflection (R)

Taylor’s reflective comments in the end-of-summer survey focused on the following:

- The action research project allowed Taylor to reflect on their teaching practice, which enhanced their KoT as a component of their PCK.
- The CHEM 776 class exposed Taylor to valuable resources and lab ideas, especially those related to environmental chemistry. This combination of their KoR and KoT indicated improvements to the quality of their overall PCK.

- Participating in two SDSU research labs enabled Taylor to pursue broader lab ideas in their own classroom. This application of their KoSc to their KoT indicated improved PCK quality.

Codebook 3

Taylor shared three comments coded as "Feedback." These statements were further analyzed using Codebook 3. These coding frequencies are shown in Table 142 below.

Table 142. End-of-Summer Survey Coding Frequencies for Summer 2 – CB3

Code	**Abbreviation**	**Frequency of Responses ($N = 5$)**	**Percentage of Total Responses (%)**
Assignment Feedback	AF	1	20
Course Feedback	CF	3	60
Program Feedback	PF	1	20

Assignment Feedback

Taylor shared a suggestion for an improvement to the electronic engagement activity in CHEM 776.

- "I liked the general idea of the electronic engagement activity but would've liked for it to involve an electronic skillset that teachers may not be familiar with in order to develop a new skillset. For example, this could include how to make a podcast episode or produce a high-quality video tutorial."

Course Feedback

In terms of course feedback, Taylor shared the value of developing and executing lab activities while on campus, including the opportunity to receive feedback from peers.

- "As a teacher, it was really valuable to be given the time and resources to develop a lab activity from scratch. To then be able to actually execute it while on campus and receive feedback was great."

They also shared the value of the morning CHEM 776 discussions.

- "The face-to-face discussions were really helpful as well. I liked being able to wrap our heads around the underlying theory of whatever lab we were discussing prior to executing it later in the afternoon."

Taylor shared positive feedback about the CHEM 788 course regarding their learning about chemical education research.

- "Learning how to formally conduct research in an educational context was really enlightening."

Program Feedback

In terms of program feedback, Taylor commented on the need for research professors to have clear expectations for the teachers they host. They also shared suggestions for how professors could involve teachers in their labs.

- "Require professors who choose to host teachers during the 2-week stay to have a clear plan for how they intend to engage teachers throughout their duration in the lab. If professors deem that teachers are not qualified to carry out certain aspects of their own research, that's understandable. However, some kind of effort should then be made to have teachers work on a challenging lab related to the research or work together to possibly generate or tweak a lab that the teachers intend to bring back to their own classrooms."

Codebook 4

Codebook 4 then allowed me to break down Taylor's statements by source of motivation. Each comment was assessed to determine the focus of the comment, either focused on the participant's learning, their students' learning, or the participant's teaching. Coding frequencies are displayed in Table 143.

Table 143. End-of-Summer Survey Coding Frequencies for Summer 2 – CB4

Code	**Abbreviation**	**Frequency of Responses (*N* = 16)**	**Percentage of Total Responses (%)**
Learning-focused	L-f	8	50
Teaching-focused	T-f	8	50

Taylor's responses to the end-of-summer survey were evenly split between learning-focused and teaching-focused motivations. An example of each coded statement is given below.

- "Though I wasn't really exposed to much content during the summer, I actually learned a great deal about environmental-related chemistry throughout my duration in the ice core research lab." (L-f)

- "As a teacher, it was really valuable to be given the time and resources to develop a lab activity from scratch." (T-f)

<u>Summary of End-of-Summer Survey</u>

In the end-of-summer survey, Taylor reflected on their second summer campus experience, especially their experience in the CHEM 776 and CHEM 778 courses. Their responses were motivated by implications for their own learning and teaching. The main themes from this survey were:

- Taylor's experience in the MS program, including their completion of an action research project, gave them the confidence to perform research in their own classroom.
- During the summer session, Taylor gained both research and chemistry content knowledge and skills through their experience in MS program courses and in an SDSU research lab. This improvement to their KoSc led to improved PCK.
- Through the CHEM 776 course, Taylor was exposed to new lab ideas, especially those related to environmental chemistry, that they could incorporate into their own instruction. Their experience on campus gave them a stronger skillset for bringing new lab experiences into their classroom. By combining their KoSc, KoT, and KoR, Taylor demonstrated improved PCK quality.
- Taylor gained valuable connections with other teachers in the MS program.
- Taylor shared positive feedback regarding the CHEM 776 and CHEM 788 courses, which emphasized the value of developing lab activities, discussing educational research articles, and learning about chemical education research methods.

- Taylor shared suggestions for improvements to the CHEM 776 electronic engagement activity. They also commented on the need for hosting research professors to have clear plans for how they will engage teachers in their lab.

Summary of Summer 2

Taylor's responses to interviews, surveys, and journal prompts demonstrated the impact of the summer component of the MS program. The main themes for their second summer in the MS program were:

- Taylor shared confidence that they could perform action research in their own classroom after completing their project for the MS program.
- Taylor formed connections with other MS program participants, SDSU faculty, and GTAs and felt confident that they could use these connections for future collaboration. Taylor expressed the value of interacting with their peers in the MS program in person, which highlighted the importance of the summer campus component of the MS program. These interactions supported Taylor's PCK and professional development.
- Taylor gained knowledge, skills, and ideas during their experiences in SDSU research labs, which they planned to bring into their lab instruction. By combining their KoSc and KoT, Taylor demonstrated improved PCK quality. Taylor brought lab ideas from their first summer into their laboratory instruction, evidencing the impact of the CHEM 776 course on their teaching. They planned to incorporate additional procedures, equipment, environmental topics, and research procedures relevant to their assigned SDSU research labs. Performing lab activities in CHEM 776 increased the likelihood that they would implement these ideas in their

classroom. Taylor gained KoSc, KoCO, and KoR from the summer campus experience, which improved their overall PCK.

- At the beginning of Summer 2, Taylor reflected on the emotional toll that balancing the MS program, teaching, family, and coaching has had on their life. By finding more balance, Taylor applied improved time management skills and made progress on their action research paper. The MS program enabled Taylor to experience professional development.
- Taylor's feedback was generally complimentary toward MS program courses and instructors. They suggested the use of an online homework system in content courses that could provide immediate feedback, as well as a greater emphasis on engaging teachers in the daily responsibilities of each SDSU research lab.

Exit

Content Exam (post-test)

At the end of Taylor's time in the program, they were invited to complete a post-content exam at which point they had taken all six core content courses for the program. The full content exam can be found in Appendix E. Proctored via Zoom, Taylor was given the exam consisting of nine past AP Chemistry free-response questions related to each of the program's content courses.[2] Taylor completed the exam in a little over 2 hours. The exam was scored using AP Exam scoring guidelines.[2] Scores for each question, course connections, comfort level rating, and confidence level rating data, along with changes between the pre- and post-tests, are shown in Table 144. The comfort level related to Taylor's comfort with the content of the question. The confidence level related to their confidence with the accuracy of their answer.

Table 144. Post-Content Exam Score and Analysis for Narrative Participant

Question	Course Connection	Point Total	Change in Score	Comfort Level Rating (1-6)		Change in Comfort Level	Confidence Rating (1-6)		Change in Confidence
				Pre	Post		Pre	Post	
1	CHEM 774	2/4	-	2	3	+1	2	3	+1
2	CHEM 775	1/3	+1	1	2	+1	1	2	+1
3	CHEM 774	5/7	-	4	5	+1	3	2	-1
4	CHEM 770/771/773	10/10	+4	4	5	+1	4	4	-
5	CHEM 770	6/6	-	6	6	-	5	5	-
6	CHEM 772/774	5/5	+2	5	5	-	5	5	-
7	CHEM 773	3/3	+2	4	5	+1	3	2	-1
8	CHEM 772	5/10	+1	5	5	-	4	4	-
9	CHEM 775	2/2	-	5	6	+1	6	5	-1

The overall score for Taylor's post-content exam was 39/50. Compared to their baseline score of 29/50, they increased their score by 20%. Changes in the accuracy of their answers will be discussed below. I will be focusing on components of questions containing errors. If not mentioned, all other questions were done correctly.

Question 1

Question 1 related to CHEM 774 content. The question involved the calculation of cell potential, indicating the migration of ions as the cell operates, mass changes of a zinc-air cell, and writing the equation for the overall cell reaction.

In the pre-test, Taylor left two problems blank, indicating that they were unable to calculate cell potential or justify why the mass of the cell increases. They wrote that they were "not comfortable" with the content and "not confident" with the accuracy of their answers. In the post-test, they made attempts at these two problems. They misidentified the potential of the anode and provided an incorrect explanation of why the mass of the zinc-air cell increases.

Although their score did not change between the pre- and post-tests, they demonstrated a greater ability to understand and answer electrochemistry problems. Their comfort level with the content and their confidence with the accuracy of their answer both increased.

Question 2

Question 2 related to CHEM 775 content. The question required Taylor to identify the hybridization of an indicated carbon atom and indicate the total number or sigma and pi bonds in an organic molecule.

In the pre-test, they incorrectly identified the hybridization of the carbon atom and did not indicate the correct number of sigma or pi bonds. They wrote that they were "not comfortable" with the content and "not confident" with the accuracy of their answers. In the post-test, they incorrectly identified the hybridization of the carbon atom and again did not indicate the correct number of sigma bonds. They did, however, indicate the correct number of pi bonds.

Along with small attitude improvements, their score increased by one point between the pre- and post-tests, demonstrating improvements to their organic chemistry knowledge, while also highlighting potential gaps in their understanding. Their comfort level with the content and confidence in the accuracy of their answer both increased.

Question 3

Question 3 related to CHEM 774 content. The question focused on reaction rates and required Taylor to calculate a reaction rate, determine the order of the reaction with respect to each reactant, write the rate law, and calculate the value of the rate constant including units.

In the pre-test, the only error was that they were not able to determine the correct order of the reaction for one of the reactants. In the post-test, they were still unable to determine the correct order for the same reactant as in the pre-test.

Between the pre- and post-tests, the same error was present regarding determining reaction order, demonstrating a potential gap in their kinetics content knowledge. This indicates that the CHEM 774 course did not fill this gap in their content understanding. Although they felt more comfortable with the content of the question, they showed a decrease in their confidence in the accuracy of their answer.

Question 4

Question 4 related to CHEM 770, CHEM 771, and CHEM 773 content. The question asked Taylor to identify properties of five given aqueous solutions, including boiling point, pH, solubility, oxidation, and conductivity. They also were asked to provided explanations of their understanding of these properties.

In the pre-test, for two of the five parts, they identified the incorrect solution, which rendered their explanation incorrect. In the post-test, they answered all five parts of the question correctly, demonstrating their knowledge of chemical properties. They were able to support their choices with accurate explanations, which confirmed an improvement to their content understanding.

Between the pre- and post-tests, Taylor gained chemistry content knowledge, as well as comfort with the content. Their confidence in the accuracy of their answer did not change.

Question 5

Question 5 related to CHEM 770 content. The question required Taylor to determine the electron configuration of a fictional element and describe the element's behavior in terms of periodic trends.

For both the pre- and post-test, Taylor answered each part of the question correctly, but did not show an aqueous compound dissociating into its ions. They showed proficiency in their knowledge of periodic trends, but the common error revealed a potential gap in their understanding of ion dissociation. They displayed both high comfort level with the content and confidence in the accuracy of their answer for both the pre- and post-test.

Question 6

Question 6 related to CHEM 772 and CHEM 774 content. The question asked Taylor to classify a reaction, discuss changes in reaction rate, and determine if the reaction was driven by enthalpy, entropy, or both.

In the pre-test, they identified an acid-base reaction as redox; however, the oxidation numbers of the species did not change. In the post-test, they provided correct explanations, demonstrating an improvement to their understanding of reaction types. Their comfort level and confidence did not change between the pre- and post-tests.

Question 7

Question 7 related to CHEM 773 content. The question asked Taylor to analyze a titration curve for concentration of species and pK_a during a neutralization reaction.

In the pre-test, they incorrectly estimated the pK_a for the weak acid and were unable to determine if the weak acid or its conjugate base was present at a higher concentration in the solution at a specific point during the titration. In the post-test, they completed each part of the problem correctly, indicating improvements to their knowledge of acid-base chemistry. They indicated improved comfort with the content, but decreased confidence in the accuracy of their answer.

Question 8

Question 8 related to CHEM 772 content. The question focused on stoichiometry and determining the standard entropy and enthalpy of formation for a given reaction.

In the pre-test, they incorrectly calculated moles of a reactant, which led to their misidentification of the limiting reactant. They were then unable to calculate the resulting moles of the product. They left the final part of the problem blank, which asked them to calculate the standard enthalpy of formation of a reactant. In the post-test, they also did not correctly complete the final part of the problem. In addition, they incorrectly calculated the standard enthalpy of formation for another reactant and did not discuss the impact of the entropy change on the spontaneity of the reaction.

For this problem, Taylor showed improvements to their stoichiometry and ability to calculate limiting reactant. For the post-test, they showed errors that were not present in the pre-test relating to thermodynamics. For both tests, they showed a gap in their thermodynamics knowledge by being unable to calculate a reactant's standard enthalpy of formation. Question 8 revealed potential gaps in Taylor's overall knowledge of thermodynamics. Taylor's comfort level and confidence did not change between the pre- and post-tests.

Question 9

Question 9 related to CHEM 775 content. The question asked Taylor to draw the structural formulas for the two additional isomers of pentane.

Taylor answered Question 9 correctly in both the pre- and post-tests, indicating strong content knowledge related drawing organic structures and their isomers. They demonstrated increased comfort with the content and decreased confidence in the accuracy of their answer in the post-test.

Summary of Content Exam (pre/post)

Their results for the content exam reveal an increase in Taylor's chemistry content knowledge resulting from their experience in the MS program. Improvements to the accuracy of their answers demonstrates increased knowledge for content from each of the MS program core courses. In the post-test, Taylor demonstrated either constant or increased comfort levels with chemistry content. For most of their answers, Taylor's confidence in the accuracy of their answers either stayed the same or increased, while their confidence in two of their answers for CHEM 773 and CHEM 775 decreased. Overall, their content exam ratings demonstrated positive attitude changes regarding their comfort level and confidence with chemistry content. The MS program content courses supported improvements to Taylor's content understanding (KoSc), as well as their comfort level with the content and confidence with their ability to answer questions correctly. By improving Taylor's KoSc, the MS program content courses enhanced Taylor's overall PCK.

Exit Survey

The exit survey gathered information about the impact of the MS program on Taylor's teaching effectiveness, knowledge and skill, and teaching. The survey also allowed them to provide feedback for the MS program, sharing aspects they found most and least valuable. The exit survey was analyzed using Codebooks 1, 3, and 4.

<u>*Codebook 1*</u>

The coding frequencies for Codebook 1 are presented in Table 145.

Table 145. Exit Survey Coding Frequencies – CB1

Code	**Abbreviation**	**Frequency of Responses (N = 41)**	**Percentage of Total Responses (%)**
Attitudes	A-c	6	14.6
Knowledge	K-p	1	2.4

	K-c	5	12.2
Skill	S-c	8	19.5
Goals	G	4	9.8
Experience	E	1	2.4
Teaching	T	5	12.2
Feedback	F	2	4.9
Interaction	I	1	2.4
Reflection	R	8	19.5

Attitudes (A-c)

Taylor described the attitudes that contributed to their high level of teaching effectiveness.

- "In short, I believe I'm highly effective due to my willingness to reflect [and] willingness to learn."

They also shared that gaining KoSc as a component of their PCK "helped [them] feel more comfortable teaching various topics."

Taylor reflected that the MS program has "positively influenced" their motivation for teaching high school science and provided the below reasoning. Thus, the MS program allowed them to experience professional development.

- "I think this is largely due to the increased level of confidence I now have on a variety of topics as well as the number of new ideas I gained as a result of the research experience, collaborations with others, and exposure to new lab ideas."

Taylor stated that they were "very glad" they chose to complete this MS program. They also stated their attitudes looking back on their experience in the MS program.

- "Genuinely [working hard] made me really proud of what I've accomplished over the past two years rather than feeling like I just jumped through another hoop."

<u>Knowledge (K-p and K-c)</u>

Taylor described being a highly effective teacher due to their PCK.

- "In short, I believe I'm highly effective due to my pedagogical content knowledge."

They discussed gaining "improved content knowledge," stating that they met one of their goals for their time in the MS program. This improvement to their KoSc led to improved PCK.

- "One of the biggest things I gained as a result of this program is content knowledge. It helped either fill in some of the gaps in my own knowledge and expand my knowledge within various topics that I had little to no experience with."

Similarly, they gained practical chemistry knowledge, which indicated improved KoSc as a component of their PCK.

- The MS program "has also really had an impact on my knowledge of measurement, accuracy, and precision."

<u>Skill (S-c)</u>

Taylor discussed the skillset that contributes to their high degree of teaching effectiveness. The MS program supported Taylor's continued professional development of these skills.

- "In short, I believe I'm highly effective due to my ability to adapt, behavioral management skills, content creation skills, and communication skills."

They then discussed skills that they gained from the MS program, including the use of lab techniques and instrumentation. They stated that they met a personal goal for the MS program by attaining an "increase in lab related skills." By gaining KoSc, Taylor improved their overall PCK.

- "Another big skillset I gained [through the MS program] was my general level of comfort with various lab techniques and measurement devices."

They also gained improved skills for data collection and analysis.

- "In general, the program has helped give me what I consider to be a better framework for gathering and analyzing data."

<u>Goals (G)</u>

Taylor described goals they met through the MS program, including improvements to their content knowledge and skill, as well as gaining new connections with other MS program participants. Taylor's statements regarding these goals are discussed in the "Knowledge," "Skill," and "Interaction" sections.

<u>Experience (E)</u>

Taylor described research experiences they had on campus, highlighting the value of participating in two different research labs. By observing both organic and analytical researchers, they were able to view chemistry research from multiple perspectives. The campus research experiences supported Taylor's development of KoSc as a component of their PCK.

- “I think one of the best things I've learned about is simply appreciating various aspects of the scientific process in action when it comes to conducting research. Though the general process is similar in all fields of science, I found it to be very valuable seeing how those with an organic background carry out ideas and techniques compared to those with an analytical background.”

Teaching (T)

On a scale of 1 to 6, Taylor rated their current teaching effectiveness as a 5. They shared knowledge, skills, and attitudes that contribute to their high level of teaching effectiveness. These MS program gains impacted their teaching. They first described how improving their KoSc as a component of their PCK has positively impacted their teaching approach.

- Gaining chemistry content knowledge “helped me consider new ways to teach such topics simply because I knew more.”

The MS program also enabled them to make changes to their pedagogy in terms of their use of labs and activities, indicating improvements to their KoR as a component of their PCK.

- “I have certainly made changes regarding the various decisions I make within my pedagogical approach (labs, activities, etc.).”

Taylor discussed the impact of their summer campus experiences on their lab instruction. They described direct impacts on their school’s lab approach and use of equipment. This combination of their KoSc, KoT, and KoR demonstrates improvements to Taylor’s PCK quality.

- "The two weeks spent on campus the past two summers exposed me to various lab equipment and ideas that have had a direct impact on how we do certain things in the lab at my school as well as some of the choices we've made about sensor equipment."

Feedback (F)

Taylor shared two comments coded as feedback. These statements were further analyzed using Codebook 3, which will be shared in the section below.

Interaction (I)

In terms of interactions, Taylor described meeting a personal goal for their time in the MS program through the "formation of relationships with new teachers for increased collaboration potential." This demonstrated their desire to utilize these connections professionally after the conclusion of their MS degree.

Reflection (R)

When discussing their teaching effectiveness after completing the MS program, Taylor felt that there is always room for improvement.

- "Though I believe I'm highly effective, I know there are always things I could work on so I don't think I could ever rate myself as a '6.'"

They also reflected that their primary goals for the program related to their chemistry content knowledge (KoSc).

- "I wouldn't say I've made noticeable changes to my pedagogical approach, but that really was never one of my goals."

Although gaining pedagogical knowledge wasn't their goal, Taylor described making new choices based on improved KoCO that could improve their teaching. This combination of their KoCO and KoT would improve their overall PCK quality.

- "I believe curriculum decisions have given me more opportunity to improve my teaching."

Connecting to their K-c and S-c, Taylor again emphasized the value of the summer campus experience. They stated gaining knowledge and skills through their research and lab experiences in CHEM 776 was unique. These opportunities allowed for professional development that could not have taken place in a different context. These experiences allowed for Taylor to develop KoSc as a component of their PCK.

- "Probably the most valuable aspect of the MS program is the two-week stay on campus during each summer. Some of the knowledge and skills gained during those two weeks I would have never experienced or acquired elsewhere and that's something that really stuck out to me."

Taylor reflected that they didn't find anything least valuable about the MS program, so they shared suggestions that will be discussed further in the Codebook 3 section below.

- "I couldn't really think of anything we did in the program that was not valuable, so I just went with something that I would've liked to see more of instead."

Taylor stated that they are "very glad" they chose to complete this MS program. Again, they discussed the positive challenge of earning this degree compared to other MS programs.

- "The fact that it was challenging at various times and demanded my time, attention, and ability to learn was something that I wanted. Compared to other MS programs I've heard about others completing, which sound like it was a breeze to complete, I really liked the degree to which I genuinely had to work to do well in this program."

To conclude, they reflected that they "would recommend this program to anyone looking to acquire a better understanding of chemistry and how they can use that information to inform and improve their own teaching practices."

Summary of Reflection (R)

Taylor reflected on their experience in the MS program and its impacts on their teaching. The main themes for reflection were:

- Although they did not have pedagogical goals for their time in the MS program, gaining chemistry content knowledge enabled Taylor to make curricular changes that improved their teaching. By combining their KoSc, KoCO, and KoT, Taylor demonstrated improvements to the quality of their overall PCK.
- Taylor emphasized the value of the summer campus experiences, reflecting that these experiences provided unique opportunities for them to gain specialized knowledge and skills. These experiences allowed Taylor to experience PCK and professional development.
- Taylor appreciated the challenge of completing this MS degree compared to other master's programs and would recommend this MS program to other teachers based on content knowledge gains and implications for improved teaching.

Codebook 3

Taylor shared two comments coded as "Feedback." These statements were further analyzed using Codebook 3. These coding frequencies are shown in Table 146 below.

Table 146. Exit Survey Coding Frequencies – CB3

Code	**Abbreviation**	**Frequency of Responses (N = 2)**	**Percentage of Total Responses (%)**
Program Feedback	PF	2	100

Program Feedback

Taylor described how MS program instructors supported Taylor's achievement of their goals.

- "Many of the goals that the MS program helped me meet were the result of Instructor A and Instructor B consistently choosing to prioritize what they brought to the program for us to develop as teachers in addition to their flexibility and transparency in communication."

Although they did not identify any aspect of the MS program as "least meaningful," they suggested something they "would've liked to see more of" in the MS program.

- "It was never communicated as being part of the program, but it would have been nice to learn more about the implementation of technology within teaching. For example, having teachers learn how to make and edit high-quality chemical education tutorials."

Codebook 4

Codebook 4 then allowed me to break down Taylor's statements by source of motivation. Each comment was assessed to determine the focus of the comment, either

focused on the participant's learning, their students' learning, or the participant's teaching. Coding frequencies are displayed in Table 147.

Table 147. Exit Survey Coding Frequencies – CB4

Code	**Abbreviation**	**Frequency of Responses (*N* = 18)**	**Percentage of Total Responses (%)**
Learning-focused	L-f	9	50
Teaching-focused	T-f	9	50

Taylor's comments were split evenly between learning- and teaching-focused motivations. An example of each coded responses is given below.

- "One of the biggest things I gained as a result of this program is content knowledge." (L-f)
- "I believe curriculum decisions have given me more opportunity to improve my teaching." (T-f)

<u>Summary of Exit Survey</u>

Taylor's responses to the exit survey indicated MS program impacts and allowed them to reflect on their experience in the MS program. They shared statements motivated by their learning and teaching. The main themes for the exit survey were:

- Taylor described themselves as a highly effective teacher due to their positive attitudes, PCK, and professional skillset.

- The MS content courses enabled Taylor to fill gaps in their chemistry content knowledge, which impacted their curricular choices and, therefore, their teaching. Improving their KoSc positively impacted their KoCO and KoT, which led to improved PCK and enhanced PCK quality through the combination of these knowledge bases.
- Taylor reflected on the value of the summer campus experiences, which allowed them to gain practical knowledge, skills, and confidence that impacted their laboratory instruction. By combining their KoSc and KoT, Taylor expressed improvements to their PCK quality. They also described improvements to their school's laboratory approach as a result of their participation in the MS program.
- Observing multiple chemistry research labs on the SDSU campus provided Taylor with new perspectives of how laboratory approaches vary across subdisciplines of chemistry. This again impacted their approach to laboratory instruction. By combining their KoSc and KoT, Taylor demonstrated improved PCK quality.
- Taylor gained new professional relationships through the MS program, which they hope to utilize for collaboration in the future.
- Completing a "challenging" MS degree allowed Taylor to feel "really proud of what [they've] accomplished," compared to other master's programs. Due to their own learning and professional development, they would recommend this MS program to other teachers.

Exit Interview

The exit interview followed up on data gathered in the exit survey, as well as discussing Taylor's completion of Summer 2 and their action research defense. The interview also invited Taylor to reflect on their entire experience in the MS program and its impact on their teaching effectiveness and PCK. Taylor provided feedback for the MS program by sharing aspects they found most/least valuable and giving suggestions for future changes. The exit interview was analyzed using Codebooks 1, 2, 3, and 4.

Codebook 1

Coding frequencies for Codebook 1 can be found in Table 148.

Table 148. Exit Interview Coding Frequencies – CB1

Code	**Abbreviation**	**Frequency of Responses (*N* = 73)**	**Percentage of Total Responses (%)**
Attitudes	A-p	3	4.1
	A-c	6	8.2
Knowledge	K-p	2	2.7
	K-c	7	9.6
Skill	S-p	2	2.7
	S-c	5	6.8
Goals	G	5	6.8
Experience	E	11	15.1
Background	B	2	2.7
Teaching	T	4	5.5
Modules	M	1	13.7
Feedback	F	5	6.8

Interaction	I	5	6.8
Reflection	R	15	20.5

<u>Attitudes (A-p and A-c)</u>

When reflecting on their defense, they shared positive attitudes regarding the quality of their action research project. They also shared positive statements related to the MS instructors encouraging them to consider publishing their work.

- “I felt very validated that a lot of the work that I put into this came out to be a quality product. [The MS instructors] didn't need to tell me anything like that as far as the publishing. The fact that they felt that way was nice, which is very affirming again.”

Taylor stated that the MS program helped them gain confidence in their KoSc, which was one of their goals. This improvement to their KoSc led to enhanced PCK.

- “What I really feel like the program gave me, which is what I wanted, was that additional confidence in content knowledge.”

Similarly, the MS program helped Taylor gain confidence teaching science practices. They described a positive improvement to their teaching confidence resulting from their MS program experience. Thus, the MS program enabled Taylor to enhance their PCK quality through their development of KoSc and KoT.

- “That's the big thing for me when I really think about it. [The MS program] has given me a better opportunity to teach those science practices with greater confidence than it may have otherwise been…It's something that I felt okay about before, but I feel even better about now.”

Taylor shared positive attitudes related to professional reinvigoration prompted by their experience in the MS program. They specifically discussed increased interest and excitement toward teaching chemistry. Thus, the MS program allowed for Taylor's professional development.

- "Being in this program, it's almost revamped my interest in science education and in teaching chemistry. It's got me excited to do it again. It was almost that spark that you needed to get you through, or to get you inspired to complete the race, so to speak, which is the career. I feel like that's really added to my general level of interest. I think that is something that I didn't totally anticipate coming into [the MS program], but it's something that I think is super valuable."

Taylor shared positive changes in their confidence relating to the pre/post content exam they took at the start and end of their time in the MS program. They also shared their current level of knowledge (K-c) that would allow them to answer questions with greater accuracy. By combining their KoSc and KoT, Taylor demonstrated improved PCK quality.

- Their problem-solving ability "varied with different levels of confidence, but I have a broader conceptual [knowledge base] to either give a plausible answer now or give the answer. I felt more confident about that."

<u>Summary of Attitudes (A-p and A-c)</u>

Taylor shared positive attitudes about the quality of their action research project. The MS program allowed them to gain confidence in their KoSc, their problem-solving ability, and their teaching. Taylor experienced professional reinvigoration through the

MS program and described increased interest and excitement toward teaching chemistry. The MS program allowed for Taylor's PCK and professional development.

Knowledge (K-p and K-c)

Taylor gained knowledge through conversations with the research professor that led their assigned SDSU research lab. Thus, these interactions supported Taylor's PCK development.

- "The knowledge that I gained in terms of conversations with [their research professor] was really nice."

Taylor described gaining knowledge over the course of their two years in the MS program, which positively impacted their overall PCK.

- "I know I have…more knowledge that I've accumulated over the past two years."

In terms of pedagogical knowledge, they discussed gaining knowledge through their literature review for their action research project. By gaining KoT, Taylor improved their overall PCK.

- "My breadth of knowledge has expanded a bit in terms of learning theory. That was largely due to all the work I had to do for my research project."

Taylor shared that the MS program enabled them to teach a "wider variety of concepts" using multiple methods for exploring those concepts.

- The MS program "has given me a better, deeper framework for approaching teaching that has made me more flexible, more adaptable, and more encompassing. I can touch on not just a wider variety of concepts, but also a wider variety of ways in which those concepts can be explored."

When reflecting no their pre- and post-content exam, they shared their prior and current levels of knowledge (K-p and K-c) that impacted their ability to answer exam questions.

- "If I wasn't right about the answer, upon getting feedback [on the post-test], I'd be like, 'oh, that makes sense now,' whereas if I was wrong about an answer in the past like on the [pre-test], and you told me why I'd be like 'okay,' because it just wouldn't make sense, like, 'okay, I get that. This is true. You do it like this instead of that.' Whereas if I got it wrong now [on the post-test], like, 'Oh, yeah, yeah, I've gone down here. And I should have done this. Oh, yeah, because that's left side instead of the right.'"

<u>Summary of Knowledge (K-p and K-c)</u>

Taylor gained chemistry and laboratory knowledge through the MS program, including interactions with fellow MS program participants and their Summer 2 research professor. The KoSc they gained enabled them to better understand content on the post-content exam. They gained pedagogical knowledge through their action research literature review. Due to the MS program, Taylor was better able to teach a "wider variety of concepts" in a "wider variety of ways." By combining their KoSc and KoT, Taylor demonstrated improvements to the quality of their overall PCK.

<u>Skill (S-p and S-c)</u>

Taylor stated that they have gained skills during their two years in the MS program.

- "I know I have more skills…that I've accumulated over the past two years."

Taylor shared their prior and current skill (S-p and S-c) regarding their ability to answer questions on the content exam. Their growth in their chemistry content knowledge enabled them to explain concepts more accurately and effectively. This demonstrates improvements to Taylor's PCK quality through their development of KoSc and KoT.

- "There would be things in the past that you could ask me about, and I would have little to no ability to give it a meaningful answer. In the past, you could ask me a particular question that I may not have had the ability to answer in any neat way because I just didn't have the mental framework established prior to the program. I couldn't have given as good of an answer, but now I feel like I have greater flexibility with being able to answer questions in any particular content field that I wouldn't have or that I wasn't as comfortable answering before. Even if I don't know the answer right on the top of my head, I at least know what to look for. I have enough of a framework in my head to give a plausible answer. I have more ways to think about things. There would be certain questions on that test, for example, that you know, I was just like 'I have no idea how to answer this' and the second time I took it, it's like 'I don't know exactly how to answer this, but I think I know how to answer it, or I know more than just guessing.'"

Summary of Skill (S-p and S-c)

Taylor gained skills through their two years in the MS program. Relating to the content exam, they expressed improved skill in terms of explaining chemistry concepts more accurately and effectively. By combining their KoSc and KoT, Taylor demonstrated improved PCK quality.

Goals (G)

Taylor described a primary goal for their two-week experience on campus, which focused on their action research paper.

- "One of my goals of spending those two weeks there is get real [sic] clear about my paper. What do I need to do? I'm not saying I needed it done by the end of those two weeks, but I needed to be in a spot where, when I do go back home, I can easily finish it on my own. I knew that there would be several instances where I would spend three to five hours in the library on campus in order for that to be done. I needed to have other tasks taken care of."

Taylor shared three ways in which they have made progress toward their goal of making contributions to science education.

- "If one of my goals is to make a contribution to science education, well, part of doing that is becoming a more well-rounded teacher, but also part of that is even something like my research."
- "If you're saying that this is potentially publishable stuff, well, that's the contribution to science education, bringing concept inventories into the light with respect to gaining clarity on what kids know versus what they don't know, and to what extent that it helps me shift or affect science education."
- "Being in the program has inspired various new ideas that I've written about on ChemEd X – the website that I write for – which has been cool.[70] And that's contributing to science education."

Summary of Goals

Taylor described making progress toward their action research paper as their main goal going into Summer 2. They also described how they have made progress toward their goal of contributing to science education, including becoming a more well-rounded teacher, conducting and potentially publishing their research, and making contributions to a chemistry education website.[70]

Experience (E)

Taylor felt that the summer research experience was valuable because they gained knowledge and skills on campus that they didn't gain elsewhere. Thus, the campus summer experience enabled Taylor to develop KoSc as a component of their PCK. They compared their experiences in an organic research lab in Summer 1 and the analytical research lab in Summer 2.

- The value of being on campus "largely alludes to the experience in the lab. I would have never had an opportunity to operate or be aware of ion chromatography or cutting [and] analyzing ice cores. Getting the experience from an analytical perspective [due to research professor's] background was really nice compared to the experience I gained from an organic perspective with [GTA] the previous year. How they operate, not just in terms of practically moving around in the lab or organizing things, but just the degree of precision and carefulness is apparent in the analytical lab that isn't as apparent in the organic lab. [The analytical research lab] was much more of my cup of tea [and] more aligned with my personality. Learning from [research professor] was really nice too."

They shared their experience working with an SDSU research professor in Summer 2.

- "I was really fortunate to have a professor that would take time out of their day to converse with us and lead us in discussions. And so that was good."

Taylor described their experience defending their action research project. They reflected on how their presentation went and responded to feedback they received during the presentation. They shared their feelings prior to and during the defense, stating that the defense was a “stress-free environment.”

- “The defense itself went a lot better than what I had first anticipated how it was going to go. It was funny because I felt like I was in a good spot with it and I didn't rehearse. You're told you're the one who knows the most about the thing that we're talking about and you don't really know what you're nervous about other than a general sense of nervousness. It was funny because once my actual presentation started, it was almost like you just flip a switch. I felt super confident and I was really happy with the speed with which I responded to questions from Instructor B and Instructor A and I was happy with my responses and I'm happy with the fact that I didn't take ten minutes to think about what my response would be. It's like if a student has a question, you already know it, like you're the expert in the room so you can be really flexible in your thinking if you understand the basic principles. I felt really good about that. I really liked how in classic Instructor A style from the get-go just makes you feel comfortable. At no point in time did I ever perceive it during the defense as feeling pressure or stress. It was a stress-free environment, so that was cool. I liked the questions. Some of them were the right amount of challenge to get you to think about certain things. I like the feedback that I got. One of the things that Instructor A was guiding me toward via questioning and I eventually got there was as good as the research project was it would have been even better had I had some qualitative data and that was something that I had gone back and forth on at various times and ended up never pulling the trigger on it.”

Along with a fellow MS program participant, Taylor shared their experience reflecting on performing action research in their own classroom that could be published.

- “Even [MS program participant] and I have talked about that. We read some of these journal articles in the course of doing your research and you're like, ‘Oh, I could do that.’ It's not that often that I came across articles from high school teachers. I often feel like they're from professors at a college level or researchers themselves, so I don't know what percentage of published articles are from high school teachers. I just thought [Instructor B’s offer to assist with publishing their action research] was really nice.”

Reflecting on their experience in two SDSU research labs, Taylor contextualized the feedback they gave in regard to expectations for research professors and GTAs who invite MS program participants into their labs. They first described their experience in their Summer 1 research lab.

- “I'm not speaking from necessarily personal experience. [Research professor] was rarely present the first year, but that was for a number of valid reasons. It wasn't like they just chose not to be there. We worked intensely with [the GTAs]. And I loved the fact that it's like, ‘Hey, we got done with [research professor’s] Vitamin C extraction research a little bit early. What do you want to do?’ ‘What do you mean what do you want to do?’ ‘Is there anything you want to implement or work on?’ And I was like, ‘can we do a caffeine extraction?’ ‘Yeah, we have the tools to be able to.’ I don't know how to do a caffeine extraction, but [GTA] does, so they helped guide me through and that blossomed into NMR and that blossomed into IR spec. Ultimately that blossomed into me for the first time ever implementing a caffeine extraction lab this past year in my Honors chem class. Even though going into [research professor’s] research team, the goal was never caffeine extraction. We were extracting flavonoids from various fruits and then that sort of segued into ‘well, what else could we extract?’ ‘Caffeine?’ ‘Okay, well, there's different solvents.’ It was never the goal, but because [GTA] was willing to work with me and we there was that opportunity and that desire, that blossomed into something much more beautiful.”

Taylor then described experiences in their Summer 2 research lab, some of which contrasted with their first summer research experience.

- “This year there for me there was a lot less that I did in the lab in terms of getting my hands dirty, but there was a lot more discussion, and I think part of that came from just [the research professor] being who they are and as knowledgeable as they are. It was such a cool experience because [the research professor] was what I envision in my head of what a scientist is. They’re so aligned to scientific principles. And to set ego aside and bias aside and to be really, really, really clear about ‘when you say this, what do you mean? You say you could measure this – how would you measure that? And even if you could measure that, to what degree of certainty can you say this with?’ And so all these things that you know, but you don't necessarily practice on a fundamental level. You could tell that was just baked into their core, and that was so cool to observe and see. I loved the fact that we got to see in front of us, [the research professor] would set [the GTAs] up. They would be teaching them in front of us and grill them in a way where it's like, ‘Hey, you need to know this stuff because you might be running your own research lab one day and you can't eff this up.' It was just really cool, but it was in a professional way. It was really eye opening to see how researchers interact. In a research lab there is this natural hierarchy where it's not like one person knows all, but one person clearly knows more than the other, that principal investigator, and everybody is doing a job but there's this continuous challenging of each other, and I got to see even simple things like they're troubleshooting the ion chromatograph where it's like, 'well, hold on. We need this data. The longer this ice sits melted in this little container, the more the data gets screwed up because you start to incorporate oxygen and other impurities and so it gets to be messed up data, so what do you do? You can't just call the guy who is in another state to come by and get it.' And 'I wrote this down in my science lab notebook.' 'Oh, you use lab notebooks too? How do you use lab notebooks?' It was a much more encompassing experience this year in terms of knowledge and skills whereas last year it was just an overall directive experience where I got to build something and establish something and so both experiences were super valuable."

Summary of Experience

Taylor described valuable experiences they had in SDSU research labs (an organic chemistry lab in Summer 1 and an analytical chemistry lab in Summer 2). Through their development of KoSc, these research experiences supported improvements to Taylor's PCK. They shared their experience collaborating with SDSU GTAs and research professors. They shared their experience defending their action research project, including how their presentation went and what feedback they received from MS program instructors. They discussed potentially conducting and publishing more action research in the future.

Background (B)

Taylor discussed the new science standards that were recently implemented in their state. This discussion of their KoCO indicates PCK.

- Teaching science practices "is such an integral part of what [state] is trying to implement with this whole three-dimensional teaching and part of that dimension is the science practices."

Taylor then described how the MS program has enhanced their career trajectory and positively impacted their passion for teaching. Thus, the MS program has allowed for Taylor's professional development.

- "Simply the act of getting a master's has helped, checking that box, so to speak, as there's [sic] more areas that I could pursue if I really wanted to besides just teaching, not that I have intentions to, but it's helped revamp – being ten years in, and now with the recent addition of two kids in the past three years, and a lot of life changes, your priorities shift, and there's a subtle chipping away of a certain passion that you had for teaching. Then COVID hit. You have all these confounding factors and variables eating away at that a little bit and getting out of the sense of 'well, another year.'"

Teaching (T)

Related to their teaching, Taylor discussed the value of discussing and implementing lab activities while on campus for CHEM 776. They especially appreciated gaining lab ideas with environmental chemistry themes. By gaining KoSc, KoT, and KoR, Taylor improved the quality of their overall PCK.

- "We would actually implement some of the labs in the afternoon. I don't know if this is Instructor A's intended purpose, but [the CHEM 776 lab activities] seemed to have much more of an environmental theme to them and that was an area that I had been lacking in with respect to labs, especially since the new [state] standards required or include more environmental chemistry connections. It was something I had always wanted to do but wasn't always aware of how to do it. Even if I don't directly implement those labs in particular, it gave me a better idea of what's possible and so that was good."

They described minimal changes to their pedagogical beliefs due to the MS program, although they did gain KoT as a component of their PCK.

- "I feel like not much has changed for me pedagogically in terms of my core beliefs about how science knowledge is constructed and learning theory."

Taylor then described how the MS program did impact their teaching, especially regarding awareness of teaching strategies and lab ideas. By gaining KoT and KoR, Taylor experienced improvements to their PCK.

- "What I really feel like the program gave me, which is what I wanted, were…ways to engage the kids in various activities, investigations, [and] pursuits of questions – things that I wouldn't likely have otherwise been aware of or may not have been aware of until years down the road. That could be something as simple as lab ideas, but it also got me thinking a lot more about how we make the lab experience more meaningful."

<u>Summary of Teaching</u>

Through CHEM 776, Taylor gained new environmental chemistry lab ideas to use in their own classroom. This gain of KoT and KoR led to improvements to Taylor's PCK. Although they described minimal changes to their pedagogy due to the MS program, Taylor shared that the MS program gave them new ideas for teaching strategies and lab activities, including how to "make the lab experience more meaningful." By combining their KoT and KoR, Taylor experienced improved PCK quality.

<u>Modules (M)</u>

Taylor reflected on the utility of pedagogical assignments in the MS program courses, including the modules, which allowed them to reflect on their teaching. This reflection allowed for PCK and professional development.

- "Whether it is the lab development class or even at various stages throughout the various content courses when you're doing something from a teacher's point of view, like the CoRe, those moments where you had to really reflect on what you're doing, or what you could do, and why you would do it – I think it has really helped."

<u>Feedback (F)</u>

Taylor shared five comments coded as feedback. These statements were further analyzed using Codebook 3, which will be shared in the section below.

<u>Interaction (I)</u>

Taylor discussed the value of knowing fellow MS program participants prior to arriving on campus and forming strong connections with other teachers.

- "I really like the fact that I was more comfortable with people that I already knew obviously. Going into a place where you at least know one person is just going to be a different experience than going into a place where you know nobody. That was helpful. Over the duration I've established a good relationship with [MS program participant] and so the fact that we got partnered up with the roommate thing was nice."

They described their second summer on campus, focusing on the value of having a larger cohort for CHEM 776. They pointed to the value of having more perspectives during conversations.

- "The fact that there was [sic] more people added a different element to it in a positive way. It wasn't like last year was bad and this year was good because there was [sic] more people, but I think [with] more people there's just more opportunities for different conversations, so that was nice."

These interactions supported Taylor's PCK and professional development.

Reflection (R)

Taylor felt that the summer campus experience "was really good…Overall it was a positive experience."

They reflected on their experience in their Summer 2 research lab, focusing on why the lab was a good fit for themselves and a peer. They described the value of being exposed to ice core research, which improved their KoSc as a component of their PCK.

- "Being part of the ice core research group was really cool. It was a really eye-opening experience. Both [MS program participant] and I are uber curious about a variety of things, but when we are curious about things, we'd tend to dive headfirst into the shallow end. It's something I always was vaguely aware of in terms of ice cores, but it was never an area of interest that I would have pursued because when am I ever going to deal with that kind of stuff? The fact that I got the got to deal with it and interact with it was really cool. It was a fun experience."

They reflected on their second campus experience in comparison to Summer 1, stating that they felt more prepared and had better time management. Thus, the MS program enabled them to experience professional development.

- "This summer I was in general more prepared. In terms of tasks and time management, I got the things done that needed to be done at an earlier date than just exploring and talking and doing other things and procrastinating and waiting 'til the last minute to do other things. I think that was partly due to the fact that I knew that I needed time for my paper."

Taylor stated that "overall [their action research defense] went well." They reflected on feedback they received from Instructor A during their defense to include qualitative data in their action research project. They discussed research findings that could have been better supported using qualitative data.

- "Thinking back, yeah, I wish I would have and that could have shed light because by the time my research was done and I'd collected the data and done the analysis, it was found that those in the treatment group where I implemented the changes showed a decreased frequency in choosing misconceptions on every single misconception that was categorized relative to the control group. In educational research I'm very reluctant to be like, 'therefore, it's because I did this,' but it gave me an opportunity to actually propose a hypothesis and then if that hypothesis was true, then we should see this. We are seeing this, so therefore it's reasonable to make this hypothesis, right? All Instructor A was trying to allude to, which I agreed with, was you'd have even more confidence in that hypothesis had you had some qualitative data to go along with what the students are saying and so that was cool. It was a nice critique that I like, and it gave me from the think about."

Taylor then reflected on the MS program instructors' suggestion for them to consider publishing their action research. They discussed how publishing their work may inspire them to publish more research in the future.

- "I was also really surprised, because it was never my intention, but both Instructor A and Instructor B, thought that it was publishable, and I thought that was cool. They said, 'even as it is right now without the qualitative stuff, I think this could be published.' And so we talked a little bit after it was all said and done about the logistics of publishing. I still have yet to decide if that's something I want to go through on. I'm not against it at all. I know that that would be an added layer of work, especially with school coming up, and it was really nice that Instructor B offered to help me with that because I think my paper ended up being like 30 pages, and so obviously you'd have to chunk up a lot of that, but just to know that I'd have some assistance – I think publishing something would be cool to have under my belt. I think it would also propel me to pursue possibly publishing something again in the future."

As with the initial survey, Taylor ranked themselves as a 5 on a scale of 1 to 6 for their teaching effectiveness in the exit survey. Taylor reflected that, although they may have become more effective, they would never mark themselves as a 6 out of 6 given their “personality” and teaching philosophy.

- “As far as the scaling goes, I don't think I'd ever mark myself as a 6 because it implies that I'm the most effective that I can be. At least that's what it says to me and that's just never true about being a teacher. I just abide by that.”

Taylor reflected on how the MS program impacted their teaching practice, stating Instructor A’s focus on modeling in various courses, which impacted Taylor’s overall teaching effectiveness.

- “In any course it's not that we ever took the time and said, ‘hey, we're going to focus on this particular practice right now.’ At various times we would, like modeling. I really liked how Instructor A in various courses would get us to think about modeling and what that means and how we get kids to model and think about ideas, and so it has caused me to think about what I do in the classroom in a more nuanced way. I feel like that makes me a more well-rounded teacher.”

Summary of Reflection

Taylor reflected that their second summer at SDSU was “a positive experience.” Their assigned research lab allowed them to be curious and explore a new research field. They came into Summer 2 with better time management skills and a goal to focus on their action research paper. They reflected on their action research, stating that they could have involved qualitative methods to support their hypothesis. They shared their interest in publishing their action research at the suggestion of the MS program instructors.

Taylor ranked themselves as a 5 on a scale of 1 to 6 in terms of their teaching effectiveness because marking themselves as a 6 "implies that [they're] the most effective that [they] can be." They also reflected that the inclusion of modeling in Instructor A's courses positively impacted Taylor's overall teaching effectiveness.

Codebook 2

Codebook 2 coding frequencies can be found in Table 149.

Table 149. Exit Interview Coding Frequencies – CB2

Code	**Abbreviation**	**Frequency of Responses (*N* = 16)**	**Percentage of Total Responses (%)**
Knowledge of science	KoSc	3	18.8
Knowledge of goals	KoG	1	6.2
Knowledge of students	KoSt	3	18.8
Knowledge of curriculum organization	KoCO	4	25
Knowledge of teaching	KoT	4	25
Knowledge of resources	KoR	1	6.2

In the exit survey, Taylor stated that they are a highly effective teacher in part due to their PCK. When elaborating on their PCK, they described their teaching in terms of their KoT, KoSt, KoSc, and KoCO, highlighting four components of their PCK. They discussed their ability to anticipate student misconceptions (KoSt) based on their understanding of the content itself (KoSc). They touched on their KoT and KoCO when referencing their collaboration with colleagues to design new teaching materials.

- "When I think about pedagogical content knowledge, this is where I feel like sometimes the rubber meets the road with some of my colleagues where I'll be talking about X when we're designing a test or a lab or an activity and it's from the perspective of what I can already anticipate areas of struggle that the kids will have not solely based on experience, because anybody can do that if you've taught for more than a year or two, but also based on what you know to be true about the concept itself, the generation of the concept."

They then discussed how their pedagogical skill (S-p and S-c) and knowledge (K-p and K-c) evolved throughout their time in the MS program. They demonstrated their KoR, KoCO, KoSt, and KoT as components of their overall PCK. The discussion forums in MS program courses exposed Taylor to new student misconceptions (KoSt). They also gained knowledge of misconceptions (KoSt) through their action research project. Their action research and participation in MS program courses broadened their PCK.

- "A lot of times in years past it would be hard for me to articulate why I would choose to make this particular decision or want to pursue this decision in anticipation of where kids are likely to fall down in this concept or why we would design this question in such a way based on common misconceptions of kids. I've always felt like I've had a fairly strong pedagogical knowledge, but what I feel like the program has helped me do – in the discussion boards, you get so much more exposure to more points of view on areas of kids falling down in various concepts, but then also that complimented with the research. Because my research was focused on misconceptions and if you're going to alleviate misconceptions or prevent misconceptions, you have to have a high degree of awareness of pedagogical content knowledge and that broadened my knowledge more deeply about the importance of it."

Taylor shared their ability to explain chemistry concepts more effectively, demonstrating improvements to their pedagogical skill (S-c) through increased KoT and KoSc as components of their PCK.

- "I feel like I can articulate better, not just the various ways in which my pedagogical content knowledge changed, but also when I'm talking about a particular thing I feel like I have more mental tools to be able to dive deeper into why this concept is the way that it is and things that we need to be aware of."

Taylor also revealed their PCK when discussing their goals for the MS program. The MS program allowed them to further develop their KoCO by focusing on the science practices involved in their state standards.

- "The program has helped me approach teaching those 7 science practices, that are primarily the NGSS ones, to implement them and to teach them and to help kids develop them a lot better, whether it is from constructing evidence-based explanations, things like analyzing data."

They discussed measurement skills they gained through the MS program (S-c), touching on their KoSc as a component of their PCK.

- “That's one thing that the program has really helped me with is the gathering of data and the analysis of the data, like measurement in general. That's one skillset that I think largely is due to the two weeks spent during the summer at SDSU just because you're in the research lab and measurement is such an important characteristic that has to be treated with respect in the lab.”

They reflected on the impact of the summer research experience, demonstrating their KoG, KoSt, and KoT related to knowledge and skills they gained in the SDSU research labs. They discussed their desire to connect phenomena to students’ “everyday experiences,” which reveals their KoG and KoSt. They demonstrated their KoT by discussing the integration of phenomena into their instruction.

- Even if I'm not using those exact instruments in my lab in the classroom, carrying over the same principles and knowing that only a small fraction of my students are going to be pursuing something in science I feel like it's helped give me more ways to connect reality and their experiences with science in a variety of ways. Because I know more now, it’s like storytelling, think about something as simple as historical stories that make connections with kids but also being aware of phenomena that is maybe more related to their everyday experiences. That can help me frame whatever it is that we're learning about to that relatable phenomenon, that relatable circumstance, or that relatable investigation.”

Taylor also demonstrated increased confidence regarding teaching science practices, which connects to their KoCO. They made connections to their teaching context and their state’s implementation of new science standards.

- "That's the big thing for me when I really think about it it's giving me a better opportunity to teach those science practices with greater confidence than it may have otherwise been and because that's such an integral part of what [state] is trying to implement with this whole three-dimensional teaching and part of that dimension is the science practices."

Codebook 3

Taylor shared five comments coded as "Feedback." These statements were further analyzed using Codebook 3. These coding frequencies are shown in Table 150 below.

Table 150. Exit Interview Coding Frequencies – CB3

Code	**Abbreviation**	**Frequency of Responses (*N* = 5)**	**Percentage of Total Responses (%)**
Program Feedback	PF	4	80
Logistical Feedback	LF	1	20

Program Feedback

Taylor's first feedback for the MS program focused on helping teachers develop better digital content creation skills. They suggested helping MS program participants learn how to use a software or create "better digital tools" to use in their classrooms.

- "It would be nice if, as part of the program, there was some kind of dedicated some kind of dedicated outreach or development to helping teachers develop better digital tools, which is a huge umbrella. I almost think of the popularity of chemistry tutorials and since almost everybody uses some kind of learning management system and there are things like e-learning days now versus snow days, having the ability to go simply beyond ‘well, here's this Khan Academy video.’ Or ‘here's this whatever video’ and give our kids something that is customizable to them from their teacher. I feel like 90 plus percent of teachers know how to make a video but aren't aware of what goes into a quality content creation video. I know that's not necessarily the skillset of those running the program, but even if it wasn't a skillset like, are there ways to pursue that? It'd be nice leaving the program being like, ‘okay, I know how to run this software.’”

In addition to creating instructional videos, Taylor suggested assistance for creating chemistry simulations or utilizing the Arduino software used in an SDSU research lab to “DIY certain sensors to meet certain needs.”[77]

- “If I wanted to develop a chemistry animation or rudimentary simulation, not like a high quality PhEt or something like that, but just some basic coding that could be done – like those Arduinos.[71, 77] When [MS program participants] were doing that for the lab development thing, my mind was just blown that you could program these little Arduinos to function as connectivity sensors and you could have the connectivity sensor read it out in the digital output. You could have it vocalized it so you could hear it audibly. You could have it show up on a computer. All these things that all of a sudden splintered off 89 other ideas or doing something like an automatic titrator. I didn't even know those things were possible. When I say digital, it could be something like creating a video, but it also could be if you don't have access or the money to buy sensors from Vernier or Pasco, how could you DIY certain sensors to meet certain needs."

Taylor's second feedback focused on SDSU research professors demonstrating their commitment to having MS program participants in their research labs by providing daily expectations for their involvement. They provided extensive feedback for why SDSU faculty should actively involve teachers in their research or lab instruction while they are on campus, indicating a symbiotic relationship.

- "I don't know to what extent this is even possible. I was very fortunate to work in research labs that were very involved, and for the most part I had stuff to do each day. In talking with other people, one thing I think the program could blossom in big time: if the two-week stay is meant to have a meaningful impact on everybody who participates in the program, there has to be some kind of requirement or expectation of the research professor that, when those teachers are here, they need to be doing something on a daily basis that's not just observing and listening. That can get really long and boring for anybody even if you're interested in it, just sitting there for 6 hours and having a lunch break in between. That's not fun for anybody and so to hear about experiences where the professor barely even engaged with the teachers that were there, it's like, 'well, what'd you sign up for? Why did you agree to have us in the first place?' That sort of thing. I think it's more of a top down thing to say like, 'hey, we have this program at SDSU. If you professors are in this chemistry program, part of your expectation is that you actually participate in this with the teachers,' and there's so many things to consider, because not all the teachers can do all aspects of the professor's research because the teachers aren't qualified to do so – that’s totally understandable. I would never expect [their Summer 2 research professor] to be totally cool with me cutting off some fraction of the ice core and then running it on my own, even if they taught me how to do so. That's not the point. Whatever you feel comfortable with the teachers doing, show them. Guide them. If there's something that can be done on the daily basis, figure out ways to do that. Even if that's not possible with respect to your particular research, then we’ve got to think of something else, like, ‘Okay, you teach high school chemistry. Is there any way for us to integrate what I'm researching with high school chemistry? Let's work to develop a lab.’ Even if it's not that like, ‘hey, I'm a college professor and therefore I likely teach labs. Here is an advanced 400-level lab that I expect seniors to do. Do you want to run through this lab and potentially evaluate it for ways in which you can make it better?’ Because having another teacher run through a lab – it's the same reason that we have all the other teachers in the program run our labs that we develop because it gives us opportunity for feedback. ‘So maybe you've been doing this biochem lab with…sophomores at the college level. Maybe you've been doing it for years. Well, have you ever run it through some kind of feedback mechanism? No? Okay, well, let me try it. And I see you doing it like this. But maybe you could do it like this instead,’ or it could be purely a pedagogical thing. ‘I see there's no opportunities for ideas to be expressed here, or you ask the kids to write a conclusion. How does that go?’ All these conversations could happen, so my larger point is that every professor is aware of the expectation that if you're a tenured professor, we expect you to do research.

There's almost a university expectation that if you are going to accept teachers to be here for two weeks, part of your contribution as a professor to the university and to science education as a whole is to help train and guide and develop and collaborate with these science educators who do what you do in terms of science education, but at a different level. We're the ones who are sending those kids to you and so we both have a vested interest in this."

They further elaborated on the need for research professors to have a better plan for the MS program participants' participation in their labs, focusing on the summer campus experience's impact on the MS program's "marketability." They then shared further suggestions for changes they would like to see in the future in terms of research professors' involvement in the summer research.

- "When I talk to people who have had good experiences in the research lab with their professor as a part of this program during that two-week session, it's because the professor is involved, and I don't know if that has to come from Instructor A or if it has to come from a university admin type of thing or what. If this is going to be a two week experience, if you're going to require a teacher to do that, then it needs to be valuable, otherwise they will not go back to their respective schools or communities and vocalize their support for others joining. It's directly impacting in a negative way your marketability if you don't have professors heavily involved in some kind of meaningful way to get teachers to develop something. Right now, I just think it's like, 'hey professors, do you want to have teachers?' 'Yep.' 'Okay, hey, you can think of an idea, or an abstract, or something like that, we could send that out to them.' And then all of a sudden, just one day these people show up and they're just there and it's like we just do stuff. Some of them have a better plan than others, no doubt, but it needs to be more than that. There needs to be a directive plan and it can't be just dished off to the [GTAs] either, I think [research professors] need to be heavily involved. The professor's time is valuable. The [GTA’s] time is valuable, so it's not to say that ‘hey, it's the summer, you don't have anything to do right, professor?’ but it's almost part of the program and not just an another thing they need to do, so I think it could be a win-win for everybody.”

Logistical Feedback

Taylor shared logistical feedback in terms of where MS program participants were housed during the two-week campus experience.

- “I like that feature, too. I like staying in that hall versus the other one. It just had a better vibe to it, and I liked that we could still have our own individual rooms but you're still in that same little space.”

Codebook 4

Codebook 4 then allowed me to break down Taylor’s statements by source of motivation. Each comment was assessed to determine the focus of the comment, either focused on the participant’s learning, their students’ learning, or the participant’s teaching. Coding frequencies are displayed in Table 151.

Table 151. Exit Interview Coding Frequencies – CB4

Code	**Abbreviation**	**Frequency of Responses (*N* = 52)**	**Percentage of Total Responses (%)**
Learning-focused	L-f	21	40.4
Student-focused	S-f	6	11.5
Teaching-focused	T-f	25	48.1

Taylor's comments in the exit interview were motivated by the MS program's implications for improvements to their teaching (48.1%) and learning (40.4%), as well as their students' learning (11.5%). An example of each coded response is given below.

- "The program has helped me approach teaching those 7 science practices that are primarily the NGSS ones." (T-f)
- "My breadth of knowledge has expanded a bit in terms of learning theory." (L-f)
- "I can already anticipate areas of struggle that the kids will have not solely just based on experience…but also based on what you know to be true about the concept itself." (S-f)

Coded as "Reflection" for Codebook 1, I asked Taylor to rank which knowledge base lays the foundation for the next in terms of their own learning (L-f), their own teaching (T-f), and their students' learning (S-f). They elaborated on their "hierarchy" below:

- "I think focusing on my own learning because I have to know it. I can't affect the students' learning if I don't understand it, whether it's the pedagogy or whether it's

> the content, so I think that I have to come before the students' learning, not because I inherently am somehow more important, but because it's almost like a prerequisite. I need to know X before the students can know, if I'm going to have any chance at teaching the students X. I think my own learning and then once I feel like I have learned it, then I think my teaching. How students learn will therefore affect how I teach, but when it comes to the program itself, I feel like what the program emphasized is the content, so I view that as my learning, and then the pedagogy, and then the increased focus on student learning. I'd probably put it in that order from the point of view of the program: valuing my learning, valuing teaching, and then valuing student learning. Because I think that those first two things then come together to then affect the student learning. To me it's not necessarily a priority thing as much as it is almost like a hierarchy. It's like a prerequisite like, 'I need to know this and then I need to be able to have the skills to be able to teach this, and then based on those things I can affect student learning.'"

To summarize, Taylor created a hierarchy of "valuing [their] learning, valuing teaching, and then valuing student learning" in terms of the MS program.

<u>Summary of Exit Interview</u>

During the exit interview, Taylor followed up on responses to their exit survey and shared their experiences during their Summer 2 campus experience and their action research defense. They also shared feedback on the MS program overall, especially feedback related to the summer campus experience. Most of Taylor's comments focused on their teaching (48.1%) and learning (40.4%), but they did include references to their students' learning (11.5%). The main themes for Taylor's exit interview were:

- Taylor gained confidence in their KoSc, their problem-solving ability, and their teaching, which improved the quality of their overall PCK. They also demonstrated increased confidence in terms of teaching science practices, connecting to their KoCO as a component of their PCK.
- Taylor gained chemistry content knowledge and pedagogical knowledge through the MS program requirements, demonstrating improved KoSc and KoT as components of their PCK. MS program courses gave Taylor new ideas for teaching strategies and environmental chemistry lab activities, revealing increased KoT and KoR.
- Taylor gained pedagogical skill and laboratory skill through the MS program requirements, with emphasis on the campus research experiences. These skills enabled them to teach chemistry concepts more accurately and effectively and create more meaningful lab experiences for their students. Taylor developed stronger PCK through improved KoSc and KoT. These skills prepared Taylor to teach the science practices integrated in their state's new science standards, demonstrating their KoCO.
- Taylor experienced professional reinvigoration through the MS program by gaining increased interest and excitement toward teaching chemistry, as well as gaining KoSc, KoT, and KoR through MS program courses and interactions with other MS program participants. Pedagogical assignments in the MS program

courses allowed them to reflect on their teaching. MS program supported their career goals and positively impacted their passion for teaching chemistry.

- Developing relationships with other MS program participants positively impacted their comfort level being on campus for the summer research experience. Interactions with other teachers in the MS program allowed for a wider range of perspectives during conversations, which impacted Taylor's KoT.
- Taylor made progress toward their personal goals for the MS program. Taylor met their goal to contribute to science education by becoming a more well-rounded teacher, conducting and potentially publishing their action research, and making contributions to ChemEd X, a chemistry education website.[70] They also improved their time management skills.
- Taylor shared positive experiences in SDSU research labs during both summer campus experiences, particularly outlining the value of interacting with SDSU research professors and GTAs. These interactions supported Taylor's PCK and professional development.
- They successfully defended their action research project and felt inspired to conduct more action research in their own classroom in the future. At the suggestion of MS program instructors, Taylor shared their interest in publishing their action research.
- Taylor became a more effective teacher by further developing their PCK during the MS program. They exemplified improvements to their KoT, KoSt, KoSc, KoR, and KoCO by taking into account student misconceptions when designing instructional materials and teaching. The discussion forums and their action

research literature review exposed them to new student misconceptions, which positively impacted their teaching effectiveness and improved the overall quality of their PCK. They were better able to explain chemistry concepts, which revealed their intertwining of their KoSc and KoT, thus improving the quality of their PCK.

- The summer research experience enabled Taylor to combine their KoG, KoSt, and KoT by engaging their students with real-world connections to chemistry content. They became aware of new ways to introduce content and adapt their current laboratory knowledge to the classroom environment.
- Taylor's overall feedback focused on the need for SDSU research professors to actively involve MS program participants in their research, either through the research itself or through engagement with activities for professor's teaching labs. They emphasized the value of having a positive research experience on the MS program's marketability. They also shared suggestions for the two-week campus experience related to incorporating opportunities for teachers to create "better digital tools," including chemistry content videos, animations, or software that could be used to meet their laboratory needs.
- In terms of Codebook 4, Taylor created a hierarchy for "valuing [their] learning, valuing teaching, and then valuing student learning" in terms of the MS program. Taylor felt that, in the MS program, they first needed to focus on gaining chemistry content knowledge. Then, they could apply this knowledge to their teaching, which could then impact student learning.

Summary of Exit Data

After Taylor's completion of the MS program, they completed the post-content exam, an exit survey, and an exit interview. These methods helped determine any changes to Taylor's chemistry content knowledge, pedagogical skill, and PCK. They also allowed Taylor to reflect on their overall experience in the MS program, including progress they made toward their goals. The main themes from these data collection methods were:

- At the start of their time in the MS program, Taylor hoped to gain content knowledge and skills that would help them teach more effectively and positively impact student learning. In their exit data, Taylor demonstrated improvements to their teaching confidence (which they hoped to develop initially), KoSc, and KoT, which indicated improved teaching effectiveness resulting from their experience in the MS program. They supported their high degree of teaching effectiveness with their positive attitudes, PCK, and professional skillset.
- They met their goal for improvements to their research skills by gaining educational research skills through their action research project and chemistry laboratory skills through their two summers in SDSU research labs. They discussed hoping to continue conducting action research in their own classroom in the future, which was one of their goals for their time in the MS program. The summer research experiences allowed Taylor to enhance their laboratory teaching approach. These research skills also supported improved KoCO by supporting their teaching of science practices in their state standards. These research skills enabled Taylor to make more contributions to science education.

- Taylor described improvements to their chemistry content knowledge through MS program courses and summer laboratory experiences. This change to their KoSc was quantified through the pre- and post-content exams, through which Taylor experienced a 20% improvement to their chemistry content knowledge. Improvements to their KoSc enabled them to explain concepts more effectively to their students, demonstrating improvements to the quality of their PCK and their teaching effectiveness.
- Through the MS program, they intended to reignite their passion and motivation for teaching that was negatively impacted by the COVID-19 pandemic. They accomplished this and expressed professional reinvigoration by gaining increased interest and excitement toward teaching chemistry. During MS program courses, they were able to reflect on their teaching practice and apply new knowledge and skills to their instruction. The MS program enabled Taylor to experience PCK and professional development.
- Taylor explicitly discussed PCK in their exit interview without prompting and demonstrated six of the seven components of PCK. They emphasized their ability to better explain chemistry concepts (KoSc and KoT) and design instructional materials (KoCO) while taking into account student misconceptions (KoSt). Relating to their summer laboratory experiences, they also discussed their desire to engage their students with real-world connections (KoG).
- Taylor developed meaningful professional relationships during their time in the MS program, which they hope to utilize for future collaboration. Taylor described connections they made with fellow MS program participants, as well as MS

program instructors, SDSU research professors, and GTAs. These interactions supported Taylor's PCK and professional development.

- Taylor's primary feedback related to the two-week summer campus experience. They hoped for research professors to incorporate more active involvement for MS program participants. They also hoped for the inclusion of opportunities for teachers to develop "better digital tools" that could support their teaching.
- Due to their own positive experience in the MS program, Taylor would recommend this program to other science teachers. Taylor emphasized the value of completing a "challenging" degree, gaining chemistry content knowledge, developing connections with other science teachers and chemists, having the opportunity to participate in chemistry research labs, and gaining new skills that they can apply to their own instruction.

Member Checking

To further validate the narrative data, a copy of this chapter was sent to Taylor for feedback regarding the alignment of this analysis to their experiences in this MS program. I was unable to obtain a response from Taylor for member checking.

CHAPTER 5: MS PROGRAM AS NARRATIVE

Study Population

Since the advent of the MS program in Fall 2008, participation has been geographically diverse. Teachers in the MS program have represented 31 states and China. The teachers who will be discussed in this chapter participated in MS program courses from Fall 2021 to Summer 2023. All participants in the MS program are in-service science teachers who desire to expand their chemistry content knowledge while staying in the classroom. By collecting data across all teachers in the MS program, I was able to talk about the overall participants in a narrative fashion. By compiling the experiences of current participants and alumni, the narrative of the MS program itself emerged on its own account.

Table 152 displays population data for each program course, excluding the narrative participant.

Table 152. Term Breakdown of Program Participant Data

Term	Courses	Methods ID Codes	Participants (term total)	
Semester 1 (F21)	CHEM 770	TS, MS, DF, EOS	28	(31)
	CHEM 771	CoRe, MS, EOS	20	
Semester 2 (Sp22)	CHEM 772	CoRe, TS, MS, EOS	19	(25)
	CHEM 778	MCR, EOS	19	
Summer 1 (Su22)	CHEM 776	SJ, ASCI, PCSS, EOS	10	(15)
Semester 3 (F22)	CHEM 774	CoRe, MS, EOS	22	(25)

	CHEM 775	TS, MS, EOS	16	
Semester 4 (Sp23)	CHEM 773	DF, CoRe, MS, EOS	21	(21)
Summer 2 (Su23)	CHEM 776	SJ, ASCI, PCSS, EOS	17	(19)

participant, across all terms of data collection, including methods used in each course. As discussed in Chapter 4, the narrative participant was involved in each of the courses listed below, but their data is excluded from the presentation of program participant data. This chapter will focus solely on data from general program participants to form a narrative of the program. For example, in Semester 1, there were 32 participants in program courses. Excluding the narrative participant, I will present data from the remaining 31 participants for Semester 1. Apart from program courses, one teacher also participated in a chemistry content survey (CCS) to gain information about content knowledge change as a result of the program's content courses from Fall 2022 to Spring 2023. The program narrative will allow for comparison to the narrative participant.

In addition to current program participants, a survey was sent out to program alumni to learn more about their reflections on their own experiences in the program and how the program has impacted them since completing their degree. For the summer sessions, graduate teaching assistants (GTAs) were also invited to complete a survey.

Coding Frequency Clarification

In this chapter, the frequency of codes will be demonstrated as the total number of teachers represented in each code. Instead of describing how often a specific code appeared in the data, it was most useful to describe whether or not the code was represented by each teacher. In this way, a single teacher's frequency of codes does not dominate the dataset and skew results. For example, if one out of twenty teachers discusses their attitudes ten times throughout a data source, the frequency will be represented as $N = 1$ to demonstrate that one teacher mentioned attitudes, instead of $N = 10$, implying that ten teachers shared information about their attitudes. Therefore, throughout this chapter, frequency will be listed as total number of teachers represented.

Semester 1

During Semester 1, teachers were able to participate in two chemistry content courses: CHEM 770 and CHEM 771. CHEM 770 focused on atomic theory and bonding. CHEM 771 focused on intermolecular interactions and phases of matter. These courses were fully online and primarily asynchronous. Optional weekly Zoom sessions were the only synchronous components of the courses. The data for Semester 1 is presented chronologically. Discussion forum threads were posted throughout the semester in CHEM 770 to gain a better understanding of how the course content impacted participants' content and pedagogical knowledge. The CoRe and Teaching Script assignments were both due near the end of the semester, along with their associated module surveys. The end-of-semester survey was sent out after the conclusion of the semester. Table 153 discusses the methods used during Semester 1.

Table 153. Semester 1 Data Collection Methods

Term	**Data Collection Methods**	**ID Codes**
Semester 1	**CHEM 770:** Discussion Forums	 DF

	Teaching Script Module Survey	TS MS
	CHEM 771: CoRe Module Survey	 CoRe MS
	General: End-of-Semester Survey	 EOS

Discussion Forums (CHEM 770)

In the Fall 2021 semester, discussion forum threads were introduced into the CHEM 770 course three times throughout the semester to learn more about how this content course impacted participants. The discussion forum questions related to the impact of the course on the teaching of specific chemistry topics, what changes participants carried out (or planned to carry out) in their classrooms, and what new knowledge the teachers took away from the discussion forums in general. Specific questions can be found in Appendix J. Discussion forums were analyzed with Codebooks 1 and 4.

<u>*Codebook 1*</u>

Codebook 1 provides general coding for the dataset. The codes and frequency of teacher responses can be found in Table 154.

Table 154. Discussion Forum Coding Frequencies for Semester 1 – CB1

Code	**Abbreviation**	**Total Number of Teachers Represented (*N* = 28)**	**Percentage of Total Responses (%)**
Attitudes	A-p	1	3.6
	A-c	18	64.3
Knowledge	K-p	5	17.9
	K-c	25	89.3
Skill	S-p	3	10.7
	S-c	2	7.1
Teaching	T	28	100
Feedback	F	24	85.7
Modules	M	1	3.6
Background	B	5	17.9
Interaction	I	28	100
Reflection	R	22	78.6

Examples of Attitudes (A-p and A-c)

The first code describes attitudes held by teachers prior to (A-p) and as a result of (A-c) participation in the MS program. Only one response from the discussion forums related to prior attitudes (A-p), with the teacher stating that before this course they found the history of the atom to be "incredibly boring." Several teachers discussed their current attitudes as a result of participation in the program (A-c, *N* = 18). Many teachers discussed changes in their teaching confidence (*N* = 9).

- "I just feel a lot more confident in my ability to teach chemistry now." – Teacher 16
- "After seeing it this summer and talking about it in the discussions I feel more confident to explain what is going on with my students." – Teacher 21
- "I have always tried to teach aspects of quantum theory but feel confident that I now have a stronger understanding that will allow me to go deeper where I need to and answer questions when curious students have them." – Teacher 3
- "I feel the confidence boost too - I feel a couple of steps ahead on some topics, instead of the "let me get back to you . . ." and then searching for an answer and still not knowing." – Teacher 27

Other attitudes related to the emotional or moral impact of participating in the program (*N* = 3).

- Participating in discussion forums "is really one of the few positive parts of my day some weeks!" – Teacher 7
- "It gives me a lot of hope seeing so many teachers like me that really care and want to do the best they can for their kids." – Teacher 28
- "I think more than anything, I am reminded of the high level of teaching that is going on around the country…The most impactful moments in my own teaching career have been when I sit in on other colleagues' classrooms and just observe. The discussion forums seem to mimic the same vibe of being in each other's classroom by reading all the stories of favorite activities and perceptions on

content. I also enjoy reading and discussing different pedagogical philosophies with a supportive and encouraging group [like] this one!" – Teacher 24

Many teachers discussed feelings of excitement, inspiration, or reinvigoration in their teaching as a result of the program ($N = 9$).

- "I agree with the invigorated feeling! This is why I love learning while I'm teaching!" – Teacher 19
- "I feel that I have an increased appreciation for this aspect of chemistry, and have had a lot of inspiration in how to make it interesting and fun for my students when I teach it in future years." – Teacher 5
- "I think the most important change due to this program is an increase in my enthusiasm for teaching Chemistry." – Teacher 9
- "Reading through the discussions this week, makes me excited to get to the quantum theory in my class." – Teacher 11
- "Honestly [this course] has given me motivation to really teach this unit, and not just skim the basics." – Teacher 7

Conversely, other teachers shared challenges or struggles that currently exist in their teaching, some noting how they would like to change for the future ($N = 4$).

- "This is my deepest fear! That I am only teaching them the surface level concepts or they are only understanding at the surface level and if they move on past my class did I give them the tools to succeed in other classes." – Teacher 7
- "This is awesome and I wish i was diving deeper into the material as you said you were doing." – Teacher 21

- "I certainly have not gotten into the in depth mathematics of it such as quantum numbers and whatnot, as I personally find this challenging…However given the time and a higher level of class, I would not be opposed to getting my feet wet with teaching it anymore." – Teacher 8

Summary of Attitudes (A-p and A-c)

As a result of this course, teachers shared attitude changes they have noticed within themselves. Teachers identified higher confidence with explaining content, greater excitement and motivation for teaching chemistry topics as a result of the program, and the challenges that they currently face in their teaching of chemistry. The most common themes for attitudes were:

- Becoming more confident teaching and understanding content after participating in the CHEM 770 course.
- Feeling more hopeful and motivated to teach chemistry after interacting with other science teachers in the MS program.
- Becoming more enthusiastic about teaching chemistry after learning the content in greater depth through the MS program.
- Demonstrating an awareness of the challenges participants face in their own teaching, such as a lack of depth in their own teaching of content.

In the CHEM 770 discussion forums, teachers felt comfortable expressing feelings with both positive and negative connotations, further demonstrating the community developed in the MS program. Teachers also gained confidence in their teaching of CHEM 770 topics due to increases in their content knowledge.

Examples of Knowledge (K-p and K-c)

The following code identifies knowledge possessed by teachers prior to (K-p) or as a result of the program (K-c). For prior knowledge, four teachers shared the lack of depth with which they covered certain concepts. Teachers 4 and 24 combine K-p and K-c by sharing how their knowledge has evolved as a result of taking CHEM 770.

- "In previous years when I covered these concepts I would generally gloss over them/not discuss the theoretical portions in super great detail." – Teacher 8
- "I normally kinda gloss over a lot of the quantum material and just focus on configuration (orbital, electron, and noble gas). Most of that was because it always seemed very disjointed. For example I never understood why the photoelectric effect was taught in this unit." – Teacher 7
- "I just started history of the atom and was able to provide a better explanation of the experiments which in the past I have barely glossed over." – Teacher 4
- "I have come to appreciate two things that I traditionally either gloss over or skip all together: Electron Affinity and Effective Nuclear Charge." – Teacher 24

Focusing on current knowledge, each teacher shared how they have gained knowledge through this course. Several teachers discussed how they are now able to teach atomic theory, periodic trends, or quantum theory in greater depth ($N = 9$).

- "The biggest change that I have made as a result of this course is being really cognizant with the depth of what I am teaching…There were lots of concepts that we discussed in this course that are allowing me to teach the content "deeper" than in years pervious." – Teacher 12

- “I would say that knowing the content you teach at a deeper level helps you cater to students who want to delve deeper into chemistry.” – Teacher 15
- “I think that this course will allow me do dive a little deeper into this topic with my students.” – Teacher 23

Similarly, many teachers discussed being able to explain content better as a result of a stronger understanding of chemistry topics ($N = 20$).

- “I think I am more aware of what I am explaining in class and personally have a deeper understanding of the topics, which helps me in explanations, examples and visuals I have used in class.” – Teacher 14
- “I feel like a much more competent chemistry teacher overall because of all of the content we have learned in this program. This has translated in AP chemistry because I can actually explain the content so much more easily and give lots of examples.” – Teacher 16
- “Through better understanding these concepts, I feel that I would be better able to explain them to students and help them make the connections to the significance they held in the history of science.” – Teacher 5

Other teachers have gained knowledge of new ways to approach the teaching of chemistry ($N = 11$).

- “The discussion forums have been a source of knowledge for me. I like seeing and learning about how other teachers are covering the different topics in chemistry. I am always trying to find new ways to teach the various topics covered in chemistry, and these discussions have given me great ideas on how I can do that.” – Teacher 11

- "One thing I have taken away from the discussions forums is how variably I can approach teaching the history of the atom." – Teacher 8
- "It changed the way I teach charges to my students." – Teacher 29
- "This class and the Gribbin text has given me some good insight into how things are deeper connected. I have been able to use some anecdotes to help connect some topics and some ideas for things coming up." – Teacher 6

Summary of Knowledge (K-p and K-c)

In the discussion forums, teachers have shared what knowledge they have gained through the CHEM 770 course, including improvements to their chemistry content knowledge and pedagogical knowledge. The most common themes for knowledge were:

- Gaining a greater depth of knowledge of topics that teachers glossed over in past instruction.
- Being able to explain content better as a result of having a deeper content understanding.
- Gaining new pedagogical knowledge through interacting with other teachers in the discussion forums and engaging with the content in new ways through CHEM 770.

Teachers gained both content knowledge and pedagogical knowledge through various aspects of the CHEM 770 course.

Examples of Skills (S-p and S-c)

The final code with prior and current components identifies skills developed by teachers. In these discussion forums, three teachers listed prior skills and two teachers listed skills developed as a result of program participation. Two of these teachers shared both prior and current skills. For Teacher 25, the course helped them gain skills to better connect chemistry topics.

- "Prior to this semester, I was always going forward and never really mentioning previous topics. I could see some connections and would bring it up, but it was seldom (especially first semester with all of the different topics covered)." – Teacher 25, S-p
- "Now though, this class has helped me really see how everything is connected, giving me the perfect opportunity to keep students from just forgetting everything they've learned in the past few months." – Teacher 25, S-c

For Teacher 27, they discussed having continuity of topics throughout the school year.

- "I really try to keep using big ideas throughout the year, once they are introduced. I was not good at this when I started teaching…" – Teacher 27, S-p
- "…but the more I learn the better I am at making things flow." – Teacher 27, S-c

The final participant discussed prior challenges with creating groups of students.

- "In the past, I have struggled with successful grouping of students - knowing their skill level and learning style/personality." – Teacher 9

<u>Summary of Skills (S-p and S-c)</u>

Teachers discussed improvement of their pedagogical skills, including how to provide better continuity of chemistry themes throughout their courses. The main themes for skills was:

- That teachers developed a better ability to connect chemistry topics throughout their courses.

Learning the content in greater depth also allowed teachers to make connections between concepts, which in turn allowed them to create a logical flow of chemistry topics throughout their courses.

<u>Examples of Teaching</u>

Through their participation in these discussion forum threads, each participant related information about their teaching, including ideas they have taken from discussions, what they typically do in their classrooms, and how the course has impacted the content that they teach. The first subset of responses related to teaching focused on content ($N = 25$). Teachers shared what content they would add to their courses, what content they currently teach, and how this course has impacted what content they choose to teach.

- “My greatest takeaway isn't necessarily about how I will cover content in the classroom, but what content I will cover.” – Teacher 5
- “I have learned more and understood more about the photoelectric effect through this course as well. I understood this enough to teach my AP students how to interpret PES data, but I never fully understood what was behind this data. Now I'll be able to explain this so much more thoroughly to my AP kids.” – Teacher 26
- “I added a lot more information talking about the history of the atom. I actually knew more about the experiments and the findings for Thomson, Millikan, and Rutherford that I think I made the lesson more enjoyable to the students.” – Teacher 25

- “In terms of content, this class has not really inspired me to change anything too severely, but there are certain topics that I will definitely go deeper into, or even just give more accurate information. – Teacher 10

Other teachers discussed pedagogy, or how they choose to teach chemistry topics (N = 20).

- “I've been using POGILs more intentionally this year. I use a catch and release method where I set a timer and have pairs of students work to a certain number, then back to big group to discuss their answers and revise.” – Teacher 16
- “I don't have my students memorize the periodic table or trends. I give them tools to interpret it, which I think leads to much deeper and valuable understanding.” – Teacher 20
- “When I teach atomic theory this year, I plan to give the students more of the real-life scientific experience. I want them to better understand what goes into developing a theory of this magnitude and how modifications can occur.” – Teacher 22
- “I would like to introduce more reading into my classroom and reading Gribbin's book gave an idea how.” – Teacher 29

The next grouping of responses related to teaching focused on ideas or activities, either presented to or taken from the discussion forums (N = 20).

- “I like this "Atom Card Sort" idea instead of just having students read or me lecture but to have them gather the data and derive this idea.” – Teacher 1
- “I honestly was thinking of changing my chem concepts first unit or two to be a book study about the disappearing spoon or Napoleon's buttons to get them

interested in chemistry and have some phenomenon and ideas to tie back to." – Teacher 6

- "I purchased the Obs-Certainers mentioned early on the program and plan to use them in a future Chem A session." – Teacher 3
- "The atomic model sort that someone posted I used and I think it went really well." – Teacher 16

The final subset of responses in the Teaching code describe methods of assessment and how this course has influenced participants to rethink how they assess their students (N = 10).

- "The biggest change right now for me is that I'm only grading what I think is important. For example, on a lab, I'm just grading their analysis and their procedure description. Everything else on the lab is helping them write these two sections, so I feel like I don't need to grade every little thing…Overall it means that grading is simpler but I'm also writing a lot more feedback." – Teacher 19
- "I also am trying to give fewer quiz, test, homework questions but focusing more on bigger picture and explanation type questions." – Teacher 24
- "I am more deliberately incorporating discussion into the courses I teach. Discussion can help students formulate ideas, revisit or reconsider material, apply concepts, and has the potential to help students connect with the material on a more personal level." – Teacher 27
- "I'm moving away from the memorization of ideas and concepts and more towards the actual realization/understanding of these things." – Teacher 16

Summary of Teaching

Responses to the discussion forums relating to teaching focused on participants' use of teaching strategies, activities, assessment methods, and what topics they decide to teach in their courses. Teachers shared how interactions with the course materials and other program participants has impacted how they teach chemistry concepts in their classrooms. The main themes related to teaching were:

- That participants plan to bring more information into their instruction as a result of the CHEM 770 course.
- That teachers have been inspired to teach chemistry topics in new ways due to assignments they have completed in CHEM 770 or through ideas they learned about in the discussion forums.
- That participants' experience in the CHEM 770 course informed how they plan to assess students in the future, such as incorporating more reading or discussion into their courses or assessing for understanding instead of rote memorization.

Participation in the MS program course allowed teachers to reflect on how they teach chemistry topics and how their teaching relates to their overall goals for student learning.

Feedback

Twenty-four teachers posted comments to the discussion forum related to feedback. Data coded as feedback was sent directly to MS program instructors.

Modules

Many of the discussion forums used for research were collected prior to any module surveys or the modules themselves, so the first several discussions did not contain any references to the module assignments. There was a single teacher who discussed an activity that they used for their Teaching Script assignment. Otherwise there were no mentions of the modules in the semester 1 discussion forum data.

Background

In the discussion forums, some teachers shared information related to their educational or teaching background or their current teaching context (*N* = 5). A selection of responses is given below.

- "I haven't changed anything this year yet because I am still trying to get my feet under me at a new school." – Teacher 20
- "My first masters was also online but didn't incorporate these kinds of discussion forums to any kind of depth at all, and were more of a Q&A on homework assignments with the profs providing much of the mental heavy lifting." – Teacher 2
- "This is my first year taking over chemistry concepts, so I don't really have a baseline to change." – Teacher 6

Examples of Interaction

Discussion forums are interactive by nature. One code that emerged from the dataset is interaction, which details how teachers interact with each other in the discussion forum, by requesting, utilizing, or sharing ideas, and how interactions with other teachers has influenced their perceptions of the program itself or how they interact with colleagues in a professional setting. Many teachers posted to the discussion forum threads to ask for, respond to, or take ideas from their peers (*N* = 17).

- "This is such a great plan! …Please send a picture once you make some of these and let us all know how it lands with the students. Great idea!" – Teacher 23

- “What kind of activities are you thinking of? I would love to implement some of them into my classroom as well!” – Teacher 10
- “Oh, great ideas! I really like how you paced out the different ways you helped students to continue to refine their perspective on the history of atomic structure. Very cool. I'm definitely going to save this to use in the future! Thanks for sharing!!!” – Teacher 28
- “Can I ask what you start with if you don't start with atomic theory? I've been toying with the idea of not starting with this as well and I'd love to see what other teachers do.” – Teacher 19
- “It always helps when people add more detail in understanding to topics. The particle in the box is an example I can think of. I went searching online for answers and got a very basic understanding of it. Several people replied to my post which helped with some confusions I was having originally.” – Teacher 14

In addition to requesting information, teachers also share ideas in the discussion forum. Several teachers offered their own ideas for how to bring new content or activities into their classrooms (*N* = 6).

- “A professor for WashU has been doing some outreach with my students after school and he used this website: [insert link to Ptable].[78] It is super cool because you can click on an element and it will show you the layered orbitals for that element and a ton of other things if you explore the other tabs at the top as well.” – Teacher 12
- “I'm also spending a little more time trying to have my students understand the quantum movement of electrons between orbitals. Usually I just talk about this

once and move on, but I'm mentioning it almost every day and showing them videos and simulations (Cosmos Episode 5 is great by the way).” – Teacher 19

- “I think the lesson went well and I even included the video we all thought was "boring" and students had some good laughs. This is far from perfect and I will pick some new links next year, but I attached the page I made in the chance it might help someone else.” – Teacher 27

The largest grouping of responses for the interaction code was associated with the impact the course/program has had by allowing for interactions between geographically diverse teachers ($N = 23$). This includes mentions from teachers that they are the only chemistry or physical science teacher at their school and explanations for why this makes the program’s opportunities for interaction more meaningful ($N = 7$).

- “The most helpful thing has been getting to know teachers across the country and learning from them…I'm only in my third year of teaching, so it has been great to connect with more experienced educators.” – Teacher 20
- “I am the only teacher in my school, and we are a small department, and having the opportunity to interact with other chemistry teachers is useful.” – Teacher 15
- Participating in discussion forums has “also been such a positive experience - I think for many of us - because it's been a place where we can all be rather vulnerable with admissions about what we might not know or understand, or have been explaining less than accurately in the past, etc. I appreciate everyone's input and openness in these areas and I know there will continue to be a lot of value in this effort going forward.” – Teacher 2

- “As always it is neat to see what other people are doing in the classroom, how you teach what we teach. Being the only chemistry teacher in my school doesn't allow me to bounce ideas off of anyone but these discussion forums do allow that opportunity.” – Teacher 1

The final set of responses about interactions surround interactions in participants’ respective professional settings. Teachers discuss how participation in the program has influenced interactions with colleagues in their professional environments ($N = 5$).

- “The most significant changes for me have been with my colleagues. Because of this class specifically, I have had many discussions with our physics teachers and biology teachers regarding the overlap of ideas and how we can blend our disciplines together with specific topics.” – Teacher 24
- “I have learned a lot from observing my colleagues teach and seeing how they use different resources and strategies. This year, I will collaborate with the math teachers; I want to see how they use the tablets and OneNote. So far, I have observed a few of their lessons, and I have gotten a few ideas to start using some fresh ideas in my classes” – Teacher 15

Summary of Interaction

Participants shared how interactions within the program have been meaningful for them personally and professionally. Program participants have been able to form relationships with other science teachers across the country and some have discussed how these interactions have informed how they interact with colleagues in their own schools. In addition, there were examples in the discussions of how the teachers interact with each other by sharing or requesting resources or by asking each other questions about content or teaching methods. The most common themes related to interaction were:

- That teachers actively interact with each other through the discussion forums.
- That teachers exchange ideas for teaching or understanding chemistry content in the discussion forums.
- That the MS program allowed for participants to find a community of other chemistry teachers, something many are lacking in their own schools.

Interacting with other teachers is a core component of the discussion forums and has been identified as a meaningful aspect of the MS program.

Examples of Reflection

The final code in Codebook 1 is reflection. Through the discussion forums, teachers are given a format through which they can reflect on what they have learned in the course, how the course content relates to their teaching, and how their participation in the program has allowed them to make progress toward their personal and professional goals. A selection of responses coded as reflection will be shared below (*N* = 22).

- "In the discussion about teaching strategies or even the debates about whether some concepts should be taught in high school chemistry classes have allowed me to reflect on what I would want my chemistry scope and sequence to look like." – Teacher 5
- "When you can really a grab students' attention then it open doors for introducing the content that you really want to get to." – Teacher 23
- "Honestly the discussion forums have greatly impacted how I think about the teaching that I am doing. I think they serve as a good form of metacognition and

introspection that I lack, as I don't often type out my thoughts or get my brain juices flowing when I am not taking classes…the forums have allowed me to be more reflective and try to approach my teaching style in a slightly different way this year which I think has been for the better overall." – Teacher 8

- "This course has made me to think about my curriculum and where I could improve it so it becomes more meaningful for students as they venture out on adventures after high school." – Teacher 11

Summary of Reflection

Teachers also used the discussion forums as an outlet for reflecting on what they have learned through the program, as well as what they have learned throughout their entire teaching careers. Besides sharing resources, interacting with each other, and discussing course material, teachers posted comments to the discussions that allowed them to process what they have learned about chemistry, teaching, and themselves throughout the course. The main theme for the reflection code was:

- That the discussion forums and CHEM 770 course overall allowed teachers to reflect on how they teach atomic theory and bonding to their students and what they aim to change in the future based on what they have learned in the MS program.

Teachers shared reflective thoughts on how they want to alter their instruction moving forward in light of new content and pedagogical knowledge.

Codebook 4

Codebook 4 was used to categorize the motivations behind the participants' comments in the discussion forums. Coding frequencies can be found in Table 155.

Table 155. Discussion Forum Coding Frequencies for Semester 1 – CB4

Code	Abbreviation	Total Number of Teachers Represented ($N = 28$)	Percentage of Total Responses (%)
Learning-focused	L-f	17	60.7
Student-focused	S-f	26	92.9
Teaching-focused	T-f	28	100

Because the prompting questions for the discussion forum were related to how the course had impacted participants' teaching, it makes sense that all teachers made statements that were teaching-focused. A selection of responses is given below.

- "I've also be intrigued by some of the labs/activities people have posted and have been trying to sift through them. My goal this year is to have one major lab per unit and focus on that lab throughout the unit." – Teacher 1
- "I've been searching for ways to connect chemistry concepts to real life and all of these discussion posts have been helping me do just that." – Teacher 25
- "When I understand the development better, I can see more connections and better integrate the ideas. I really try to keep using big ideas throughout the year, once they are introduced. I was not good at this when I started teaching, but the more I learn the better I am at making things flow." – Teacher 27

Almost all the participants (N = 26, 92.9%) featured comments that revealed student-focused motivations related to their teaching. Some examples are given below.

- "My students are finally becoming more confident in their predictions and are beginning to be willing to step outside of their comfort zone - memorization and regurgitation of facts or ideas. I'm really trying to push them to make those connections before seeing the answer they were hoping for. It is tough for me and for them, but I think it will be worth it in the end." – Teacher 16
- "Any strategy that helps students rely less on memorization and more on links to other chemistry concepts is a win for them. This also helps move students away from the idea the chemistry is all about memorization." – Teacher 15
- "Looking at the program overall, I really like that it is online and has been tailored for teacher's weekly schedule! It actually made me think about my students' schedule and try to be more flexible for them too." – Teacher 29

When discussing course takeaways and impacts to their teaching, 17 teachers (60.7%) shared thoughts on how they have been impacted as learners, mostly focusing on content knowledge gains because of the CHEM 770 course. Learning-focused remarks are shown below.

- "I went searching online for answers and got a very basic understanding of [the particle in a box]. Several people replied to my post which helped with some confusions I was having originally. Now after actually completing that section in the homework, I feel I have a greater understanding as well." – Teacher 14
- "Hearing other people's perspective is so helpful for me when I try and master some of these more difficult concepts. I have personally been able to conceptually

wrap my brain around some of these concepts by reading others' take on the idea or someone being able to give an analogy of how they 'see' the idea or concept." – Teacher 24

- "I have enjoyed the opportunity to update, expand, and refresh my knowledge in this course." – Teacher 4

Summary of Discussion Forums (CHEM 770)

Through the discussion forums in CHEM 770, teachers were able to discuss the impact of a content course in the MS program on their learning and teaching. All the teachers shared teaching-focused motivations, while a large majority (92.9%) gave statements fueled by their desire to improve and learn for their students. Many participants (60.7%) shared thoughts on what they gained through the MS program and CHEM 770 as learners as well. The main themes for the CHEM 770 discussion forums were:

- Participants shared positive feelings such as excitement and increased motivation for participating in the discussions with other teachers and being able to teach chemistry concepts in greater depth due to increased content knowledge (KoSc). This combination of their KoSc and KoT indicated improved PCK quality. Teachers also shared challenges and struggles they identified in their teaching related to the course's topics.
- Participants shared that they can teach CHEM 770 topics in greater depth and are able to explain the content better due to stronger content understanding (KoSc). By combining their KoSc and KoT, participants demonstrated improved PCK quality. Through the discussion forums, teachers also gained new pedagogical

knowledge and skill (KoT). Improvements to their KoT indicated improvements to their overall PCK.

- Teachers discussed curriculum organization of their atomic theory units (KoCO) and how this has been impacted by new content knowledge from the courses (KoSc), as well as new teaching ideas from colleagues that were presented in the forums (KoT and KoR). These combinations of knowledge bases demonstrated improved PCK quality.
- Some teachers also shared how the MS program course impacted their perspective on how they assess students (KoA). This improvement to their KoA indicated improved PCK.
- All teachers discussed the impact of being able to interact with other educators in the program, whether by discussing chemistry topics, teaching methods, or struggles they face in their teaching. Most participants ($N = 23$, 82.1%) discussed the positive impact of finding support through a new network of teachers in the program. These interactions allowed participants to experience PCK and professional development.

Through their discussions in the CHEM 770 course, teachers demonstrated enhancement to their overall PCK, as well as improvements to the quality of their overall PCK.

CoRe

In Fall 2021, the CoRe was administered in CHEM 771: Intermolecular Interactions & Phases of Matter. The CoRe was analyzed using Codebook 2 to assess participants' PCK. Table 156 displays the codes from Codebook 2 that appeared in the semester 1 CoRe.

Table 156. CoRe Coding Frequencies for Semester 1 – CB2

Code	Abbreviation	Total Number of Teachers Represented ($N = 20$)	Percentage of Total Responses (%)
Knowledge of science	KoSc	20	100
Knowledge of goals	KoG	19	95
Knowledge of students	KoSt	20	100
Knowledge of curriculum organization	KoCO	20	100
Knowledge of teaching	KoT	20	100
Knowledge of assessment	KoA	20	100
Knowledge of resources	KoR	20	100

The CoRe assignment was created to gain information about participants' PCK, so it is not surprising that most codes were present in each of the responses. As mentioned in the literature review chapter, researchers have been encouraged to investigate the quality of PCK, not only its existence or quantity.[43] Based on the design of the CoRe, all participants should have prior PCK.

Examples of KoSc

The first component of PCK represented in the CoRe is KoSc, which includes science content, scientific practice, the nature of science, and scientific progress.[41] In the CoRe assignment, participants discussed a challenging topic related to intermolecular interactions and phases of matter that they would like to teach. The participants also shared intentions for student learning, what additional knowledge the participant knew beyond what they would teach in the classroom, and what difficulties or limitations are involved with teaching their chosen topic. Although all responses were coded as KoSc, many responses overlapped with KoSt or KoT. This is a trend throughout the coding, demonstrating the true nature of PCK as a combination of knowledge bases.

All challenging topics were chosen based on the course content of CHEM 771: Intermolecular Interactions & Phases of Matter. Participants identified a challenging topic and explained why they found it challenging to teach. The most chosen topics were VSEPR theory and molecular shape/polarity ($N = 8$) and intermolecular forces ($N = 6$). The remaining 6 participants chose the following topics: "sea of electrons," electron configurations, changes of state of matter, kinetic molecular theory of gases, real vs ideal gases, and structure-property relationships. Some discussed that their chosen topic was challenging to teach due to struggles in their own understanding of the content.

- "I am a person who struggles with 2-D to 3-D modeling and I know that many students share this struggle." – Teacher 9
- "I chose this topic because it is one I personally struggle with sometimes which can make me self doubt [sic] if I am teaching it properly." – Teacher 14

- "The kinetic molecular theory of gases (KMT) has been something I still consistently struggle to understand and therefore, teach." – Teacher 16
- "I do not completely understand all of the ins and outs of intermolecular forces" – Teacher 11

Other explanations focused on challenges in terms of student understanding, many connecting to knowledge of their own students.

- "Students struggle with understanding what energy is and how energy is related to motion, temperature, and how these relate to states of matter and changes of state." – Teacher 3
- "My students struggle most with conceptual parts of chemistry (they work best with hands-on concepts)." – Teacher 19
- "It can be a difficult topic for students to visualize. My students are visual learners, so I would have to come up with activities that would allow them to learn the best way they know how." – Teacher 11
- "Students usually can do the math problems associated with ideal gas laws, but struggle when applying the effect of a real gas will have on different situations." – Teacher 1
- "Students often have difficulty drawing/visualizing the molecule (especially if there are lone pairs)." – Teacher 34
- "This is challenging because it is hard for students to visualize intermolecular structures and interactions." – Teacher 21

Some challenges arose due to the nature of the content itself.

- “This is one of those areas in chemistry that doesn't always have hard and fast rules.” – Teacher 28
- “Polarity of molecules is one of the most challenging to teach to my students because it is very abstract, and it does not always follow a set of ‘rules’.” – Teacher 17
- “This is a concept that you need to understand intermolecular forces along with math concepts.” – Teacher 1

Participants then shared intentions for student learning, which included learning outcomes for their chosen topics. Some examples are given below.

- “Students will learn to predict molecular and geometric shapes based on the number of valence shell electrons.” – Teacher 13
- “At this end of instruction over this topic, students should be able to draw a valid Lewis structure for a molecule, determine the correct molecular geometry, determine bond polarity, and synthesize this information to determine if that particular molecule has a net dipole.” – Teacher 28
- “Students must be able to interpret the relative strengths of intermolecular forces between molecules.” – Teacher 7

After discussing student learning outcomes, teachers then shared what additional knowledge they possessed beyond what they would teach to their students. A selection of responses is given below.

- “I wouldn’t use numerical values of kJ/mol to compare intermolecular or intramolecular bonding, just qualitative rankings.” – Teacher 19

- "A couple of topics related to intermolecular forces I won't intend students to know yet include potential energy curves and any calculations that come with intermolecular forces." – Teacher 11
- "How these forces also dictate other colligative properties other than changes of state such as vapor pressure, viscosity, etc." – Teacher 3

The next portion of the CoRe assignment related to difficulties or limitations associated with teaching their chosen topic. Many teachers discussed the challenge of visualization.

- "It is very hard to visualize something that occurs on microscopic level." – Teacher 29
- "VSEPR can be a hard concept to visualize, since we are talking about molecules that students cannot physically see." – Teacher 10
- "It is sometimes difficult to visual[ize] the interactions between the different forces." – Teacher 11
- "Visualizing water at a molecular level and 'seeing' the intermolecular interactions is also challenging." – Teacher 18

In terms of limitations, some teachers discussed the limitations associated with using models.

- "Molecular and geometric shapes can only be represented with makeshift models…no repulsion forces can be mimicked between plastic balls or between gummy bears where electrons should be exerting forces." – Teacher 13
- "Anything that asks a student to use a model of a concept as opposed to be able to directly observe it is a challenge." – Teacher 3

- "It's hard for [students] to visualize where electrons are and how they move. Many of them are stuck on the model of an atom that looks like planets orbiting the sun." – Teacher 23

Summary of KoSc

To demonstrate their KoSc, participants shared content knowledge that they had gained through the CHEM 771 course. Teachers discussed the challenges and limitations of their chosen topics, both from their own perspective as learners and from the perspective of their own students. Some teachers provided more depth to their explanation of additional knowledge than others, thus demonstrating more detail and understanding of the content. The most common themes for KoSc were:

- That visualizing concepts at the molecular level, such as VSEPR theory and intermolecular forces, is difficult for students to understand and difficult for teachers to teach.
- That teachers are aware of content knowledge related to intermolecular interactions that is beyond the scope of the courses they currently teach.
- That teachers understand the challenges their own students face with chemistry content and this understanding informs learning objectives and teaching strategies.

Statements related to KoSc demonstrated teachers' understanding of new content knowledge in the context of their own teaching. Through the CoRe, teachers applied new knowledge to their teaching of a challenging concept and viewed this concept through the lens of their own students' abilities and understanding.

<u>Examples of KoG</u>

The next code for the CoRe assignment relates to KoG, which may include learning goals for scientific literacy, real-life application, and integrated understanding.[41] This code specifically aligned with the prompting question for the importance of learning the concept. Many of the teachers discussed the interconnectedness of chemistry concepts and how their knowledge of a particular concept will translate to additional chemistry topics. Knowledge of one chemistry concept will lay the foundation for other concepts to come. These responses also relate to KoCO, or how they scaffold the concepts that they teach.

- "Molecular polarity is an important characteristic that influences many important physical properties that we will be discussing later on in the class." – Teacher 28
- "So many of the concepts that we ask the students to understand later in the course hinge on a very solid understanding of how and why some molecules are polar." – Teacher 17
- "These concepts are the steppingstones for many of the concepts in organic chemistry and other chemical reaction-based classes." – Teacher 7

Some teachers connected the importance of teaching a particular topic to real-world applications.

- "Like so much in chemistry, this explains the world around them...ultimately I want my student to walk away from my class with a deeper understanding of how their world is a manifestation of chemistry concepts." – Teacher 19
- "It is important because these students are going to be going into industry, trade, military, non college jobs. They will need to have a basic understanding of how

properties of substances change in terms of melting boiling etc based on structure and why." – Teacher 6

- "It is important for students to know this because life exists due to the properties of water and hydrogen bonding." – Teacher 18

Summary of KoG

The KoG that teachers possessed focused mainly on incorporating real-world examples for their students, as well as providing foundational knowledge that would support students later in the course or in future science learning. Through these comments, teachers shared their personal teaching philosophies for their intentions for student learning. One teacher did not share their goals for student learning, which shows a gap in their PCK for their chosen topic. The most common themes for KoG were:

- That teachers desired to emphasize the interconnectedness of chemistry topics and provide foundational knowledge for their students to draw from later.
- That teachers are aware of how high school chemistry instruction may impact students' future understanding of the world around them, as well as knowledge that can be used in the workforce.

Teachers in the MS program understand the utility of comprehending chemistry topics both for students continuing in formal science education and for students pursuing alternative careers. Participants demonstrated their commitment to give students tools to understand the world around them and provide foundational knowledge for general science literacy.

<u>Examples of KoSt</u>

The next code is KoSt, which may focus on different learning levels, needs, interests, prior knowledge, ability, learning difficulties, and misconceptions.[41] Each teacher shared the intended student learning context for teaching this specific lesson. All teachers chose to teach their topic in a high school chemistry course, with 50% ($N = 10$) choosing to teach an AP Chemistry class. The next component of the CoRe asked teachers to share their knowledge about students' thinking based on experiences and interactions they have had with students in the classroom. Some teachers described students' prior content knowledge, or lack thereof.

- "Students know atom structure and how ionic bonds form (metal with nonmetal)." – Teacher 29
- "At this point, students will have basic knowledge of how bonds are created, how to draw Lewis Dot structures and what trends are on the periodic table." – Teacher 14
- "Before coming to AP chemistry, students will have been introduced to the basic gas laws: P,V,T and the ideal gas law using moles." – Teacher 16
- "Students may not have had any prior chemistry instruction." – Teacher 18

Instead of focusing on specific content knowledge, some teachers shared their knowledge about how their students learn or think in their classroom.

- "My students like visuals and models, which is great knowledge for this unit." – Teacher 10

- “Students learn best hands-on. I will need molecular building kits in order to demonstrate polarity and for students to use while they are practicing determining polarity.” – Teacher 25
- “Ultimately my students are a curious bunch. If I can connect IMF to curiosities they already have, then this would be a successful unit.” – Teacher 19

Other teachers focused on how they can focus their teaching methods based on what they know about their students.

- “My knowledge will influence my teaching because I will want to find activities that allow my student to visually see what is happening.” – Teacher 11
- “In many of their previous science classes…they do not have to explain why the thing they are seeing are happening, just what is happening…Because of this I prep them at the early concepts and try to instill exploratory based labs to get them use [sic] to being more worried about having to be able to explain what is going on vs know what is going on.” – Teacher 7
- “I know I have to have visuals and I need to have a manipulative. I cannot do a simulation, every simulation I have tried with this year’s group has been an epic fail.” – Teacher 6

When asked to shared factors that influence their teaching, some teachers discussed factors from their students’ perspective, including limitations in their students’ understanding, student interest, and misconceptions. These statements combined their KoSt and KoT, thus demonstrating improvements to the quality of their overall PCK.

- “Since this concept is hard for students to visualize, it tends to be boring for them.” – Teacher 23

- "Depending on the students in the class and their passions or interests, I would try to frame my teaching on this idea to fit with their interests in order to help them see why it's worth it, beyond any exam, to understand this idea because of how it applies in their lives." – Teacher 2
- "Other factors that would influence my teaching is the students background information about the topic." – Teacher 11
- "Students have misconceptions about forces and bonds and I may have trouble getting them to the idea of what IMFs actually do without doing a short physics review first." – Teacher 6

Summary of KoSt

Throughout the CoRe table, all teachers were able to demonstrate knowledge of their own students, including students' prior knowledge, how students may react to certain teaching methods, and how their students learn best in their classroom. Many teachers discussed their own personal motivations for utilizing resources and procedures that best suit their students and support positive learning outcomes. However, some teachers focused on general student learning while others discussed specific student reactions or interactions that they have experienced in their own classrooms. The most common themes for KoSt were:

- That teachers recognize how their students learn best based on an acknowledgment of students' prior knowledge and observations of student behavior in the classroom.
- That teachers have a desire to adjust their instruction to best fit students' needs.

Participants demonstrated knowledge of their own students by expressing an understanding of their students' needs and how teachers can alter their own behavior to better suit their students' learning preferences.

Examples of KoCO

The next code relates to KoCO, which may include knowledge of state and local standards.[41] In the CoRe assignment, teachers are asked to name the standards that are relevant to their chosen topic. The standards varied based on the participant's current teaching context. Some chose to include standards from the Next Generation Science Standards (NGSS) ($N = 10$).[79] Others named AP Chemistry learning outcomes ($N = 3$).[2] Some teach at schools that use state-specific or standards other than NGSS ($N = 6$). A couple of teachers named replacements for standards due to the nature of the school as a post-secondary or project-based institution ($N = 2$).

Summary of KoCO

All teachers were aware of what types of standards are used in their respective teaching contexts and provided the standards that were relevant to their current teaching situation. Half of the teachers included NGSS standards, while others used AP Chemistry learning outcomes or state standards. The teachers that did not have a standardized set of guidelines discussed their personal goals for student learning based on their institution's recommendations. The most common theme for KoCO was:

- That teachers are aware of the standards that guide their instruction and can adjust their teaching of content to meet these standards.

Although participants indicate the standards they are required to meet based on their district or department's guidelines, they continue to employ creative teaching strategies to teach the content in a way that is interesting and engaging for their students.

Examples of KoT

The next code is KoT, which involves the discussion of teaching methods and activities.[41] First, teachers were asked to share the teaching procedures related to their chosen lesson. Each teacher outlined multiple activities that they would like to use when teaching their given topic. Several teachers wanted to include a laboratory activity or demonstration in their instruction ($N = 9$). Others wanted to focus on modeling, either as hands-on activities or utilizing technology such as PhET simulations ($N = 12$).[71] Group work, including process oriented guided inquiry learning (POGIL) activities, was mentioned as a teaching strategy ($N = 5$).[80]

After discussing their teaching procedures, the participants were asked to share the factors that influence their teaching. Some teachers shared factors from the teacher's perspective, such as limitations to their own teaching or understanding and teacher attitudes.

- "Because KMT is something I struggle to understand, it will be difficult for me to answer student questions and guide them to a better understanding." – Teacher 16
- "It is important to me as a teacher for students to understand how Energy works and whether it is given off or absorbed." – Teacher 14

- “I think a big factor that isn’t often discussed is teacher interest. If a teacher is interested in a topic, and brings that enthusiasm to class, I think students can tell and respond.” – Teacher 19

Other teachers mentioned logistical challenges or inherent limitations to the teaching methods they have chosen to utilize for this topic.

- “Other factors that influence my teaching is time allotted and time of the year… I also have to remember that for some of these students they learned online last year and are not at the same level as their peers who learned in person.” – Teacher 7
- “Limitations of modeling.” – Teacher 29

Summary of KoT

The CoRe allowed teachers to outline specific instructional methods they would use when teaching their chosen topic. All teachers shared teaching strategies or activities they would plan to use. Some teachers simply listed the procedures they would carry out in their classroom, while others gave more detail explaining why they chose to teach using these methods. The factors influencing their teaching related both to their own limitations and attitudes. Participants also discussed potential student misconceptions, further highlighting their depth of content understanding. These sections of the CoRe showed differences in the quality of teachers’ PCK between those who stated the foundation of their teaching plans and those who explained why certain teaching procedures should be used based on various factors related to their current teaching context. Examples are given below of two teachers who identified Think-Pair-Share as a teaching procedure. One teacher identifies the activity, while the second teacher elaborates on the utility of the activity and how it would impact student learning.

- “Think-Pair-Share about water and oil and why they don’t mix.” – Teacher 34
- “Think-pair-shares: A great way to get students involved in lecture or whole group discussion. In the beginning it is awkward but after the first few week’s students get over the initial shyness and learn to talk to at least one person in class.” – Teacher 7

The most common themes for KoT were:

- A desire to incorporate labs, demonstrations, and modeling into their instruction of chemistry concepts at the molecular level.
- That teachers are aware of how their own limitations and barriers to student learning both impact how they teach, including gaps in content knowledge, disinterest, or misconceptions.

Teachers were able to identify specific teaching strategies they would employ when teaching a challenging topic, but recognize the challenges posed by themselves as teachers and learners and by their students. Some teachers simply stated teaching procedures, while others provided a deeper rationale for how these teaching strategies best suit both the instructor and learner.

Examples of KoA

The next code is KoA, which details teachers’ knowledge of formal and informal assessments and feedback.[41] Responses related to assessment arose when teachers shared which teaching procedures they had planned for this lesson, as well as the question related to assessing student understanding/confusion. Multiple teachers included assessment methods in the teaching procedures section of the CoRe ($N = 7$). Some examples are given below.

- "Exit Ticket - medium to easy Lewis structure as individual assessment of ability" – Teacher 9
- "Before moving onto IMFs, I will quiz students over drawing Lewis structures, VSEPR notation, and determining polarity to assess if they are ready to continue on. If not, then before moving on to the next section, I will spend some of class time going over the misconceptions that have arised [sic]." – Teacher 25
- "To finish the ADI [Argument-Driven Inquiry] process, they would set up an argumentation session and be able to share their findings to their peers and practice being able to justify their results with classmates." – Teacher 21

For the CoRe prompting question asking teachers to specify how they would assess student understanding or confusion, participants explicitly shared how they would approach assessment for this lesson. Relating to student confusion, several teachers discussed the importance of identifying existing misconceptions that should be corrected before moving forward with further instruction ($N = 9$).

- "I would listen to students for any misconceptions or confusion in getting through those concepts." – Teacher 14
- "One great way to gauge student understanding is to have a specific talk with them. Asking students to explain energies levels and how valance electrons are the focus of ionic and covalent bonding. They do this in their own words and it would provide a good assessment of what they know and any misconceptions." – Teacher 23

- "I would participate in the lab activity and give guiding or probing questions to each group. During this time, I would be able to see what misconceptions the students would have, which I can then address in the moment and later." – Teacher 11
- "I ask the groups a series of questions and check their understanding, have them refocus or reedit what needs to be fixed or correct any misconceptions and move onto the next activity." – Teacher 7
- "In the POGIL, student misunderstandings are addressed immediately through class discussions." – Teacher 10

In discussing assessment of student understanding, teachers reiterated the types of procedures they would use for their chosen topic. Many teachers identified exit tickets or practice problems as a method for checking student understanding ($N = 10$). Other teachers focused on small or large group discussion to assess student understanding or confusion ($N = 11$). For this section of the CoRe, some participants did not describe assessment methods specifically, but shared which components of the content they would be sure to check for understanding before moving on ($N = 3$).

Summary of KoA

KoA was present in all participants' CoRe submissions, however, it was difficult to identify if all the teachers viewed these methods as assessment methods. For example, as the research analyst, I could identify which components of their lesson plans were objectively considered assessment methods; however, in terms of PCK quality, it is important to know if the teachers understand how they are formally and informally assessing their students. Various teaching methods that could be categorized as assessments were mentioned in the teaching procedures sections but were not clearly identified by the teachers as assessment methods. Therefore, some teachers demonstrated higher quality PCK from their KoA than others. Many teachers also shared how they would address student misconceptions. The most common themes for KoA were:

- Most teachers chose to use practice problems or discussions to check for understanding and identify student misconceptions.
- Many teachers identified assessment methods within their teaching procedures, thus demonstrating the need for assessment within lesson design.

Teachers included methods for assessing student understanding or confusion in their CoRe, but many participants did not explicitly reveal an understanding of assessment. For example, teachers included discussions as methods for identifying misconceptions but may not have fully understood the role discussion can play in assessing student learning.

Examples of KoR

The final code in Codebook 2 relates to KoR, which discusses materials and activities that teachers utilize in their classrooms.[41] Many different resources were shared in the teaching procedures section of the CoRe. Some teachers shared links to activities or videos that they use during instruction. Others described using POGIL activities or technological resources like PhET simulations or WebMO, a computational chemistry software.[71, 80, 81]

Summary of KoR

For the CoRe assignment, references to resources were given throughout the assignment, as no question specifically requested teachers to list relevant resources. Participants shared resources that they would plan to use when teaching this topic when introducing their teaching procedures. The teachers used a variety of self-developed activities, activities or labs from educational developers, online technological resources, or videos that are used to support classroom instruction. The most common resources teachers identified in their CoRes were:

- Labs, simulations, or demonstrations teachers plan to use during instruction.
- Activities to engage students during class, such as POGIL assignments or videos.

Teachers demonstrated KoR they currently use in their classrooms, as well as where they could go to find more resources. Some teachers used resources they learned about through the CHEM 771 course or associated discussion boards.

Summary of CoRe Data

In CHEM 771, all teachers were able to create a CoRe for their topic. Across all seven codes, teachers demonstrated their ability to combine these PCK bases to combine their content knowledge, pedagogical knowledge, and contextual knowledge to provide the best instruction for specific groups of learners in their classrooms. This combination of knowledge bases demonstrated improved PCK resulting from their participation in the CHEM 771 course. Participants adjusted their teaching to provide an appropriate level of content that will benefit students moving forward. Teachers used resources that best fit their teaching context and goals for student learning. The CoRe assignment allowed teachers to reflect on their instruction of a challenging topic. Responses varied in level of detail and reflection, but PCK was present for all participants. The main themes that appeared in the Semester 1 CoRe were:

- Teachers were able to design a lesson on intermolecular interactions that best suited their students. By combining their KoSc, KoCO, KoT, and KoSt, teachers demonstrated improvements to the quality of their overall PCK.
- Participants combined and connected multiple content and pedagogical knowledge bases in order to demonstrate high quality PCK.

Module Survey – CoRe

After completing the CoRe assignment, teachers were invited to complete a survey about their experience creating a CoRe for their topic. Twenty teachers completed the CoRe module survey in Fall 2021. In the survey, participants were asked if they would feel comfortable teaching their chosen topic without preparation. Of the 20 teachers, 11 (55%) would not feel comfortable, 2 (10%) would feel comfortable, and 7 (35%) would feel comfortable teaching without preparing beforehand but did not think it was a good teaching practice to do so. When asked about their confidence level on a scale of 1 to 6 for teaching their concept, the average confidence score was 4.71. Upon creating a CoRe for their topic, 6 teachers (30%) did not find it challenging and 10 (50%) did find it challenging, with 4 of these teachers finding only some aspects to be challenging. The CoRe module survey was coded using all Codebooks 1 and 4.

<u>*Codebook 1*</u>

Coding frequencies for Codebook 1 are given in Table 157.

Table 157. Module Survey Coding Frequencies for Semester 1 CoRe – CB1

Code	**Abbreviation**	**Total Number of Teachers Represented (N = 20)**	**Percentage of Total Responses (%)**
Attitudes	A-p	2	10
	A-c	12	60
Knowledge	K-p	3	15
	K-c	14	70
Skill	S-c	2	10
Teaching	T	20	100
Feedback	F	11	55
Modules	M	18	90
Interaction	I	4	20
Reflection	R	18	90

Examples of Attitudes (A-p and A-c)

Two teachers commented on attitudes they had prior to the course and 12 (60%) discussed current attitudes. Prior to the course, one teacher mentioned not feeling comfortable teaching their challenging topic without preparation. Another teacher also mentioned feeling "nervous" to teach their unit before completing the CoRe assignment.

The comments related to current attitudes focused on teaching confidence and teaching attitudes. Five teachers reported needing growth in their teaching confidence, whether by gaining more teaching experience or developing stronger content understanding through practice.

- "I always will probably need a refresher and would not be able to wing it." - Teacher 6
- "I need time to work through many more Lewis structures before I feel confident enough to teach it." – Teacher 9
- "Ultimately, I feel that I just need a few more years of education under my belt and I would feel extremely confident teaching VSEPR going forward." – Teacher 10
- "If I had more years of experience teaching it then I would feel more comfortable." – Teacher 23

Six teachers shared increased levels of content knowledge through their participation in the program, including the CHEM 771 course and the CoRe module.

- "Also, as I move through this SDSU program I'm learning a lot and feeling more comfortable." – Teacher 23
- CHEM 771 "has helped with my confidence to be able to teach" the topic. – Teacher 21
- "My confidence in teaching the topics [CHEM 771] covers has grown a lot." – Teacher 25
- "By providing a more comprehensive understanding of IMF I feel more confident in explaining what is going on with changes of state." – Teacher 3

Four teachers indicated that the CoRe module had influenced their current teaching motivations and attitudes toward teaching their challenging topic. A couple of examples are given below:

- "This model has given me more motivations to teach these concepts with the time they deserve. I did not think it was a big deal and that you could just mention them, but after going over the concepts I feel more confident in my understanding of the properties and how IMF shape them, as well as new sense of spirit to really try and make this concept not a throw a way topic but a topic worth covering in detail." - Teacher 7
- "I'm not sure if it will feel transformed, but there is certainly going to be a sort of renewed feeling that comes about whenever a lot of reflection is given to a topic shortly before teaching it…A new perspective often reveals some obvious things I was missing before." – Teacher 2

Summary of Attitudes (A-p and A-c)

In the CoRe survey, two teachers expressed prior attitudes of feeling uncomfortable or nervous teaching their challenging topic prior to the CHEM 771 course. Five teachers remarked that they would feel more confident teaching in the future if they gained more experience or content knowledge. Six teachers also shared feeling more confident due to increased content knowledge after participating in the CHEM 771 course. Teachers also discussed a shift in their attitudes toward teaching their chosen topic, including more positive feelings of motivation and increased reflection. The most common themes for attitudes were:

- Expressing a desire to feel more confident in their teaching abilities by gaining more practice with the content and teaching.
- Having increased content knowledge after taking CHEM 771.
- That teachers gained the ability to teach a challenging topic more fully after gaining new content knowledge and reflecting on their lesson through the CoRe assignment.

The CoRe exposed gaps in teacher confidence and current lessons over intermolecular interactions, but teachers also demonstrated positive attitudes toward future teaching.

<u>Examples of Knowledge (K-p and K-c)</u>

Three teachers discussed their prior knowledge and 14 (70%) discussed knowledge changes they experienced through the MS program. The teachers who shared comments on their prior knowledge described a lack of content knowledge in intermolecular forces.

- "I feel as though in my previous chemistry class only scratched the surface of intermolecular forces" – Teacher 11
- "I'm embarrassed to admit how little I emphasized intermolecular forces." – Teacher 9
- "This was always one of my own personal worst subjects in chemistry" – Teacher 6

Regarding current knowledge, there was an even split between teachers who felt they needed to learn more about their topic before teaching it in the future and those who commented on feeling adequately prepared by the content knowledge they gained through the program. A selection of responses for those who felt they needed to learn more is below:

- The CoRe "highlighted my own inadequacies that I have with this topic. It showed me where my own misconceptions and misunderstanding within the concept are at." – Teacher 11
- "Even I need the rules of VSEPR to support my thinking sometimes." – Teacher 13
- "I think after this course I need to sit down with the content some more and work through it." - Teacher 6
- "I did not really realize how much I struggled with [kinetic molecular theory] until the last test we took. I thought I understood but I was wrong. [The CoRe] has definitely made me realize that my knowledge of [kinetic molecular theory] is incredibly limited." – Teacher 16

The other half of teachers described the knowledge they had gained through the CHEM 771 course.

- "I've learned more details about [intermolecular forces] and structure/properties of matter that I wouldn't have considered prior to the class." - Teacher 18
- "The content in this course had helped me better understand the why behind some of these concepts." – Teacher 7
- "I feel like I have a better personal understanding of the material." – Teacher 19
- "In this course I have finally been able to merge many of the concepts necessary to get a full understanding of IMF and feel I have better background knowledge able to provide a comprehensive explanation of these concepts." – Teacher 3

- "I definitely have a better understanding of intermolecular forces now that I'm taking 771. Especially in my understanding of molecular geometry." – Teacher 23

Summary of Knowledge (K-p and K-c)

Three teachers discussed low prior knowledge on topics related to intermolecular forces prior to taking CHEM 771. About half of the participants felt that they need to continue to improve their content knowledge, as taking the course and completing the module highlighted weaknesses in this content area. The other half of teachers described that they have a better understanding of concepts after taking CHEM 771. The most common themes of participants' knowledge were:

- Some teachers lacked content knowledge in intermolecular forces prior to taking CHEM 771.
- The CoRe highlighted weaknesses in teachers' content knowledge and teachers felt they needed to strengthen their content knowledge moving forward.
- Teachers described gaining content knowledge of intermolecular interactions topics through CHEM 771.

Teachers are aware of where they would like their content knowledge to be after being exposed to higher level content in CHEM 771 and reflecting on these topics through the CoRe.

Skill (S-c)

Two teachers discussed current skills that they have gained through the CHEM 771 course.

- "This course has strengthened my teaching abilities in intermolecular forces, gas laws, and molecular forces." – Teacher 1

- The course content "has also gotten me to think about how I would approach these topics in a hands-on activity, going so far as to making me make a lesson plan." – Teacher 7

The two teachers described improvements to their pedagogical skill.

<u>Examples of Teaching</u>

All twenty teachers made comments in the CoRe survey related to their teaching. Many teachers discussed how the module and course overall impacted how they bring these concepts into their classroom.

- "Honestly us talking about steric numbers and expanded octets was a great reminder of how much further this content goes then what I teach in class and help encourage students what else they will learn if they continue on in chemistry." – Teacher 10
- "I enjoyed making this module because it is making me think about upcoming topics in my class before I get to them. What is hard is trying to figure out a way to bring IMF's down to students that have 0 chem background and a lower history of academic achievement." - Teacher 6
- The module "helped me think about different ways/media students can learn and better understand the studied topics" - Teacher 29

Other teachers discussed the teaching of the content in relation to their students.

- "AP students will appreciate the higher-level thinking that they will use when I present them this layer of content." – Teacher 25
- "My teaching of this concept will be less 'rote' and more hands-on and investigative. I want students to come to the understanding of how and why bonds

are polar and how that affects molecular polarity on their own instead of me just giving them a set of rules to use to determine polarity." – Teacher 17

Participants also talked about the role their level of content knowledge has in their teaching.

- "Because I struggle to understand the concept as their teacher, it will be difficult for me to assess their understanding and address specific questions and misconceptions related to the topic." – Teacher 16
- "I feel like I have a better personal understanding of the material. I think this would translate well to a better teaching of the material to my students, as long as I had time to prepare and make sure that I'm working at their level (and not teaching them grad-level concepts that might be overly difficult at their stage of chemistry learning)." – Teacher 19

Some teachers discussed how this exercise impacted their curriculum or how their chosen topic fits into their teaching overall.

- "This is a common concept that I must teach each semester and it's always on the forefront." – Teacher 23
- "In doing this CoRe assignment I realized that I have inadvertently been flipping my activities involving Lewis structures and bond polarity. It makes much more sense to introduce bond polarity before Lewis structures as then students will be building on the concept of electronegativity to determine which element belongs in the middle of a given structure." – Teacher 28
- "This module would be beneficial for someone writing curriculum, a new teacher, or someone transition into a different level of teaching. I am planning on teaching

AP chemistry and this would be beneficial for my upper level units that I am not as comfortable with teaching." - Teacher 1

The final category of comments on teaching focused on assignments, activities, or resources teachers found either through the CHEM 771 course or by way of creating their CoRe.

- "In my research for activities, I found a post on ChemEd X that taught VSEPR using an NGSS approach, and I also found a post that uses models and PhET geometries first to help students understand Lewis structures rather than the 'traditional' Lewis model first method. I found these ideas intriguing and bookmarked them for later. Because this is the topic that I find the most difficult to teach, it is hard to know if there is a better/best way to teach it." – Teacher 9
- "I did not realize the simplicity of gummy bear and toothpick modeling could be so easy, cheap, and effective until I watched one of [Instructor B]'s lectures. [Instructor B] downplayed its usefulness but I think it was really cool!" – Teacher 13
- "I have never used the molecular geometries POGIL, but through using this module it made me think of how I introduce the topic and an inquiry assignment could be a good way to do so." – Teacher 10
- The module "made me think of more hands on/discovery activities for students to engage in." – Teacher 14
- The module "made me think about how I can visualize the topic for students to make it more interesting for them (ping pong balls)." – Teacher 29

Summary of Teaching

All twenty teachers discussed their teaching. Many teachers mentioned that completing the module helped them organize their thoughts on how they would approach instruction of their chosen topic. Participants discussed the impact their level of content knowledge will have on their students' learning, whether it be a low level of understanding or a strong grasp of the concepts. Teachers were able to adjust their curriculum through completion of this module and thought of new activities they could use through their own research or ideas presented in CHEM 771. The most common themes for teaching were:

- That teachers are aware of limitations in their content understanding and their students' prior knowledge and this limits their teaching ability.
- That teachers were able to utilize new activities and resources, such as models or simulations, that they may use in future instruction.
- That teachers improved their curriculum organization of their chosen topic by thoroughly reflecting on their teaching of these topics.

The CoRe enabled teachers to think about how they need to teach their topic in the future.

Feedback

Over half of the teachers (N = 11) shared feedback on the module assignment and CHEM 771 course. Data coded as feedback was sent directly to MS program instructors.

Examples of Modules

Almost all the teachers (90%) shared comments on the CoRe module assignment itself. This was expected as the survey was focused on the module itself, however many of the comments discussed the specific impact of interacting with the material through the module activity. Many of the comments discussed how the CoRe allowed teachers to reflect on how they would introduce a challenging topic to their students.

- "This module has caused me to think about how I teach…This also made me consider why I teach this topic. Why is it important? How does it relate to the rest of the course?...This assignment has made me realize that students will utilize that information not just immediately, but also later in the course." – Teacher 25
- "This model has given me more motivations to teach these concepts with the time they deserve." – Teacher 7
- "The module has definitely transformed my teaching of this concept because it made me look at and talk about how I will be able to incorporate it into my classroom. I had no idea where to start with this topic, but by following this module, it has given me a starting point. I now have a better idea of where I can introduce this into my current curriculum, and how I will be able to help my students understand the concepts. It is like I just filled out a roadmap to the basic understanding of intermolecular forces." – Teacher 11

The CoRe allowed participants to think about new ways to approach their chosen topic in their instruction.

- "I don't think that this CoRe was challenging to create, although it was thought provoking. This gave me a chance to really analyze the topic and come up with a couple new ways that I can go about teaching VSEPR." – Teacher 10
- "In doing this CoRe assignment I realized that I have inadvertently been flipping my activities involving Lewis structures and bond polarity. It makes much more sense to introduce bond polarity before Lewis structures as then students will be

building on the concept of electronegativity to determine which element belongs in the middle of a given structure." – Teacher 28

- "I have never used the molecular geometries POGIL, but through using this module it made me think of how I introduce the topic and an inquiry assignment could be a good way to do so." – Teacher 10

Teachers also identified which aspects of the CoRe were difficult for them to complete and why.

- "What is hard is trying to figure out a way to bring IMF's down to students that have 0 chem background and a lower history of academic achievement." – Teacher 6
- "Thinking about the students thinking/knowledge was the most challenging part because I had never thought in that way before." – Teacher 34
- "The only thing that was personally difficult for me to complete was specific ways of ascertaining students' understanding or confusion around this idea (include likely range of responses). Thinking in terms of a student can sometimes be difficult but is beneficial for teachers." – Teacher 1
- "The reason [creating a CoRe] is challenging is because it is not easy to think of what your students will think – but that is a worthwhile investment of time as a teacher." – Teacher 13
- "It was challenging because it took a lot of time to think about my most challenging topic and write the CoRe." - Teacher 9

Ultimately, teachers commented on the utility of creating a CoRe for challenging concepts.

- “This tool is useful for thinking about unit design and what you want to do and why.” – Teacher 18
- “This module has helped by completely thinking through a topic and why it’s important instead of just teaching it because it comes next or because it is in the standards.” – Teacher 34
- “The Module certainly offered a way to reflect on what I’ve done in the past and how I might re-structure the topic in a more effective way and get better results with the students working through it in this way.” – Teacher 2
- “I had never heard of Content Representation (CoRe) before taking this course, but it definitely helped to change my thinking about topics I have not covered yet. I can see why CoRe is a thing, and how it can help teachers to set up concepts inside of their class. I would consider doing this myself for all new topics I come across that I want to incorporate into my teaching.” – Teacher 11
- “Performing the CoRe assignment for this topic was still very beneficial as it allowed me to piece together all of my strategies into one cohesive timeline.” – Teacher 28

Summary of Modules

Most of the participants (90%) remarked on the modules themselves. Many shared how the CoRe allowed for reflection on how they would approach teaching their topic. Multiple teachers shared that anticipating their students’ knowledge or thinking was the most challenging aspect of the CoRe. Several teachers found new activities or teaching strategies to use when introducing their topic. Participants also mentioned how creating the module was useful for thinking through their lesson design in detail to create a well-connected unit. The main themes related to the modules code were:

- That the CoRe allowed teachers to reflect on why they teach certain topics and how they plan to approach instruction in the future.
- That ascertaining student understanding or confusion was the most challenging aspect of the CoRe to complete.

Participants emphasized that thinking about their students' thinking was challenging because it forced them to approach their lesson from a new perspective.

<u>Interaction</u>

Four teachers discussed the impact of interactions on their teaching and learning. Each discussed how interacting with other teachers would help them gain confidence.

- "This is unlikely, but if there was another AP Chemistry teacher who I could review the material with or ask questions for confirmation [would make me feel more confident]." – Teacher 25
- "The collaboration, the chance to bounce ideas around with the rest of the students taking the class via the discussion boards, and the personal focus on content for my own growth and improvement have all just been refreshing." – Teacher 2
- "I know I would benefit from learning from others in the course about best practices." – Teacher 9
- "Within the continued research, talking to peers or colleagues would help [me feel more confident]. Using their knowledge as a guide, would help me develop my curriculum in a way students would understand." – Teacher 11

Each discussed how interacting with colleagues would help them become more confident in their content knowledge and pedagogical knowledge.

Reflection

The final code for Codebook 1 is reflection. Many comments have been discussed in relation to the modules and teacher attitudes relating to reflection, as almost all the teachers (N = 18, 90%) shared reflective thoughts on their experience completing the module and the CHEM 771 course overall. A selection of responses is given below.

- "I think I will always feel less than completely confident on challenging topics just because there are always the memories of the kids who don't seem to make all of the connections when the end of the year rolls around and they share the things they're still overlooking and struggling." – Teacher 2
- "I think creating lessons to challenge the students to build their knowledge through their own critical thinking will be useful in my classroom." – Teacher 34
- "So often as teachers, we get into a groove and just teach in whatever way seems to work best without thinking deeply about the pedagogy. This course helps me think more deeply about HOW to teach and WHY to teach concepts a certain way." – Teacher 17
- This module "has opened my mind to more possibilities with this concept and make me dig deeper into why I want to teach this way for my students." – Teacher 21

The CoRe allowed teachers to reflect on how and why they teach a concept, as well as how they go about planning lessons.

Codebook 4

Codebook 4 then allowed me to break down the teacher statements by source of motivation. Each comment was assessed to determine the focus of the comment, either focused on the participant's learning, their students' learning, or the participant's teaching. Coding frequencies are displayed in Table 158.

Table 158. Module Survey Coding Frequencies for Semester 1 CoRe – CB4

Code	**Abbreviation**	**Total Number of Teachers Represented (*N* = 20)**	**Percentage of Total Responses (%)**
Learning-focused	L-f	14	70
Student-focused	S-f	17	85
Teaching-focused	T-f	20	100

Most of the teachers demonstrated all three motivations in their comments. All twenty teachers shared comments that focused on their teaching. A selection of responses is given below.

- "I want to take my time with these concepts; however, I know we normally need to rush try and make sure we at least cover everything before the testing season begins which is always two weeks before the end of the school year." - Teacher 7

- “This course has strengthened my teaching abilities in intermolecular forces, gas laws, and molecular forces.” - Teacher 1
- “So often as teachers, we get into a groove and just teach in whatever way seems to work best without thinking deeply about the pedagogy. This course helps me think more deeply about HOW to teach and WHY to teach concepts a certain way.” – Teacher 17

Most of the teachers (*N* = 17, 85%) also expressed student-focused motivations. Some examples are given below.

- “If I didn’t prepare for this topic, I would be doing my students a disservice. I would end up leaving them with more questions than they started with.” – Teacher 11
- “However, I don’t think lecturing is the best way to teach a concept like this. Students need to have the opportunity to develop their own practices, struggle with the material, and ask questions if they need to.” – Teacher 28
- “I think creating lessons to challenge the students to build their knowledge through their own critical thinking will be useful in my classroom.” – Teacher 34

Several of the participants (*N* = 14, 70%) discussed the module in terms of their own learning of the content. Some examples are provided below.

- The CoRe “highlighted my own inadequacies that I have with this topic. It showed me where my own misconceptions and misunderstanding within the concept are at.” – Teacher 11
- CHEM 771 “has helped a lot with my understanding of the topic.” – Teacher 21

- "I definitely have a better understanding of intermolecular forces now that I'm taking 771. Especially in my understanding of molecular geometry." – Teacher 23

Summary of Module Survey – CoRe

Through the CoRe module survey, teachers expressed how their content and pedagogical knowledge bases have been impacted by what they have learned through the CHEM 771 course and by completing the CoRe assignment. The module survey did not allow for all teachers to overtly demonstrate their PCK, but some teachers did express goals, curricula, teaching strategies, and resources they possess for teaching their topic, as well as how knowledge of their students informs their teaching. All twenty teachers shared comments from a teaching perspective, while 85% expressed student-focused motivations and 70% presented thoughts focused on their own learning. The main themes that appeared in the CoRe module survey were:

- The CoRe gave teachers an opportunity to reflect on their teaching of challenging topics. This reflection on their KoT enabled participants to enhance their PCK.
- The CoRe assignment allowed teachers to think about CHEM 771 topics from their students' perspective. By combining their KoSc and KoSt, teachers improved the quality of their overall PCK.
- The CoRe exposed gaps in teachers' content and pedagogical knowledge bases. This demonstrated areas of potential growth in terms of teachers' KoSc and KoT.

Through the CoRe module survey, teachers reflected on their experience completing the assignment and how this exercise fit into what they have gained from the MS program overall, including new content knowledge and reflection on their current teaching efficacy.

Teaching Script

In Fall 2021, the Teaching Script was administered in CHEM 770: Atomic Theory & Bonding. The Teaching Script was analyzed using Codebook 2 to assess participants' PCK. Table 159 displays the codes from Codebook 2 that appeared in the Semester 1 Teaching Script.

Table 159. Teaching Script Coding Frequencies for Semester 1 – CB2

Code	**Abbreviation**	**Total Number of Teachers Represented (*N* = 26)**	**Percentage of Total Responses (%)**
Knowledge of science	KoSc	26	100
Knowledge of goals	KoG	26	100
Knowledge of students	KoSt	26	100
Knowledge of curriculum organization	KoCO	25	96.2
Knowledge of teaching	KoT	25	96.2
Knowledge of assessment	KoA	18	69.2
Knowledge of resources	KoR	26	100

Just like the CoRe assignment, the Teaching Script assignment was created to gain information about participants' PCK. Like the CoRe, many of the Codebook 2 codes were present in participant responses, as all teachers should possess prior PCK.

Examples of KoSc

The first component of PCK represented in the Teaching Script is KoSc, which includes science content, scientific practice, the nature of science, and scientific progress.[41] As with the CoRe, participants discussed a challenging topic related to atomic theory and bonding that they would like to use for their Teaching Script. There were two general topics that were most chosen for this course. The first topic related to electron configurations and quantum numbers ($N = 10$). The second topic focused on atomic theory and the history of the atom ($N = 9$). The remainder of the participants chose to focus on periodic trends, quantum mechanics, and significant figures. Several teachers chose their topic due to challenges related to student understanding or interest.

- "I have felt that my students did not understand the reasoning behind the periodic trends and just memorized the direction of the arrows on the periodic table." – Teacher 26
- "I find [significant figures] difficult because students struggle with the relevancy of the topic and how it applies to real world situations." – Teacher 14
- "Students have a hard time grasping the lack of technology that the scientist had available to them to come up with these theories." – Teacher 1
- "Quantum numbers is probably the most challenging concept for me to teach because where the curriculum fits in, students have not quite grasped the

knowledge of abstract material that cannot be see in the macroscopic world and therefore cannot be manipulated or examined in person." – Teacher 25

- "The reason why I believe [electron configurations] is challenging is because students generally don't care for it." – Teacher 11
- "I have found every year that I teach [electron configurations], students struggle to make sense of the pattern that is made clear by the periodic table. It is a very difficult concept for students because it is something they have never seen before" – Teacher 16

Some teachers shared why they found it challenging to teach their chosen topic from a teaching perspective.

- "Wave-Particle duality of light because I have never taught it before" – Teacher 29
- "I chose history of the atom because throughout much of this course I was against teaching it but now I am coming around, and my whole department is on the boat of not teaching much history of science for any of the courses." – Teacher 6

For others, simply the nature of the content itself posed challenges.

- "I think teaching orbitals would be the most difficult because it is such an abstract concept that it can be hard to visualize." – Teacher 20
- "This is challenging due to the abstract nature of this topic and the mathematical component." – Teacher 7

Teachers were then asked to share their prior knowledge of their topic, therefore detailing their content knowledge ($N = 17$). Some misunderstood the question and named sources of their chemistry knowledge, including prior education or teaching experience ($N = 7$).

After sharing prior knowledge, the participants discussed additional knowledge that they do not plan to include in their instruction of this topic but would share with more curious students if asked. A selection of responses is given below.

- "I will provide supplemental videos, links to more information, and an activity that asks kids to make a case for which scientist they think contributed the most." – Teacher 27
- "The more curious would probably like to see more about the d + f orbitals. I could find more videos that go beyond what my teaching script shows." – Teacher 20
- "I think it is important to show students videos of the different technology they used. Example: Most students do not understand what applying alpha particles at gold foil would look like." – Teacher 1

The final question for the teaching script related to KoSc required participants to list the fundamental components of their chosen concept. A selection of responses is given below.

- "Students should recognize that electrons will 'fill' orbitals of lower energy first; that electrons will spread out to fill up an orbital before pairing; and that they will have 'opposite' spins because electrons have the same charge." – Teacher 16
- "I believe the fundamental component of this concept of the history of the atom is that the scientific method allowed experimentation and critical thinking to uncover bit by bit the nature of the atom, which we are still not fully understanding today." – Teacher 13

- "The fundamental components would be the parts of the atom, their properties, mass, location, and place on the periodic table." – Teacher 23

Summary of KoSc

Teachers shared the content knowledge they gained in CHEM 770 related to their chosen topic and identified foundational components of the topic. Forty-one percent of the teachers misunderstood the prompt to share their prior knowledge of their topic, instead sharing sources of past knowledge. In addition, participants also shared what content they could share with more curious students above what they plan to use for typical instruction. The most common themes for KoSc were:

- Teachers found it most challenging to teach electron configurations, quantum numbers, and atomic theory due to lack of student interest and real-world examples.
- Teachers were able to identify and explain the fundamentals of their chosen concept, thus demonstrating their chemistry content knowledge.

Multiple prompting questions for the Teaching Script focused on teachers' KoSc and all participants were able to outline their content knowledge relevant to their chosen topic.

Examples of KoG

The next code for the Teaching Script assignment relates to KoG, which may include learning goals for scientific literacy, real-life application, and integrated understanding.[41] Teachers were first asked to explain the importance of learning their chosen concept. Many teachers discussed how their topic provides foundational knowledge for future science courses.

- “This is an important concept that will come up again and again in other science classes these students take…understanding this lesson will help them through their other high school classes, as well as future college classes.” – Teacher 26
- “This is an important concept for students to understand because of all the areas it can be tied to in chemistry.” – Teacher 11
- “Electron configuration is an important concept in chemistry. Students who take chemistry in high school, or college will need to know how to write compounds and complete chemical reactions.” – Teacher 32
- “This would also prepare students who are university bound for their college chemistry course.” – Teacher 5

Additionally, some teachers connected this foundational knowledge to other chemistry topics that would appear later in their course, showing how chemistry concepts are interconnected.

- “Atomic Structure and Electronic Structure are important for students to understand because it lays the foundation for where the electrons are located around the nucleus, how electrons behave, and how electrons interact with other atoms in chemical bonding.” – Teacher 24
- “Electron configuration can help students make sense of the trends we study related to the periodic table. But it also reveals the nature of atoms and how electrons can account for many of the properties of elements.” – Teacher 16
- “This concept is important as it is the foundation for chemical bonding. It also is important for recognizing trends of the periodic table.” – Teacher 9

Teachers were then asked to provide a real-world connection to their topic (*N* = 17). Some examples of responses are given below.

- "A real-world connection for students would be measuring tire pressure. The way a pressure gauge works, it is impossible to measure the tire pressure without letting out some of the air, thus changing the pressure in the tire by measuring it." – Teacher 22
- "Some real-world connections for students would be how it relates to light. I can tie this topic to fireworks, movies, and camping. In each of these situations, the atoms involved will emit visible light at certain frequencies and wavelength." – Teacher 11
- "The real-world application we will have explored is light emitted by atoms using the flame test of salts and gas discharge tubes and how they relate to fireworks and old-fashioned "neon" lights." – Teacher 9
- "Many of the students in our district follow a construction-based career path. They will encounter a variety of measurement devices in those career paths. If they have the knowledge of how the device they are using can affect the accuracy in their measurement, that will help them better understand which device to use and to know if their measurements are accurate or not." – Teacher 14

The remaining responses stated that real-world connections were difficult or impossible to find for their chosen topics (*N* = 3).

<u>Summary of KoG</u>

In terms of KoG, participants discussed how their topic relates to real-world connections that can be shared with their students, as well as how their topic relates to other chemistry or science concepts. Many delved into why it was important to introduce this topic to their students, particularly relating to future career or educational paths. The main themes for KoG were:

- Teachers felt that their chosen topic was important for their students to learn because of its role later in the course or in future chemistry courses, revealing teachers' goal to prepare students for further education.
- Two-thirds of the teachers provided a real-world connection to their topic, while the remaining teachers did not answer the question or responded that there were no real-world examples for their topic. This demonstrates teachers' ability, or lack thereof, to apply their content to a new context.

Examples of KoSt

The next code is KoSt, which may focus on different learning levels, needs, interests, prior knowledge, ability, learning difficulties, and misconceptions.[41] The participants shared the student learning context for this particular lesson. All but one teacher chose to teach their topic in a high school chemistry course, ranging between introductory chemistry to Honors or AP courses.[2] The remaining teacher chose to teach the concept in a physics course.

Teachers were then asked to share misconceptions that may arise when engaging students with this topic. A selection of responses is given below.

- "Students usually struggle with understanding the technology that was used at that time. Students struggle with comprehending those theories changed over time." – Teacher 1

- "A couple of misconceptions I can see coming up would be that electron configurations can only be written for ground state electrons, and the electrons always filled the energy levels, sublevels, and orbitals the exact same way every time." – Teacher 11
- "Students often think that a theory is 'just an idea' and that when a theory has more proof, it eventually becomes a law." – Teacher 27

After discussing misconceptions, teachers shared what reactions or questions they expected from their students throughout this lesson. Some questions that the teachers expected related to the content specifically.

- "How small is an atom?" – Teacher 13
- "What is a polar molecule?" – Teacher 26
- "What are atoms made of?" – Teacher 12

Other questions related to the importance, purpose, or relevance of what the students are learning.

- "Why are we learning this? What is this used for? Will this pop up again in the future?" – Teacher 7
- "Why do I need to know this/when will I ever use this?" – Teacher 16
- "What is the purpose of learning this?" – Teacher 14

Some potential questions revealed student curiosity about how scientific theories or techniques are developed.

- "How can scientists be sure that it is true?" – Teacher 29
- "How did Heisenberg come up with this?" – Teacher 22
- "How do we know this? What if it is wrong?" – Teacher 4

Summary of KoSt

Participants demonstrated KoSt by offering examples of questions that may come up during the lesson on their challenging topic. Some potential questions related to clarifying questions or curiosity about the scientific process. Other reactions aligned with the purpose of learning these concepts. The most common themes for KoSt were:

- That teachers are aware of potential misconceptions that could arise in their classroom, demonstrating an understanding of their students' prior knowledge.
- That teachers were able to anticipate student reactions based on prior experiences in their classrooms.

Teachers demonstrated their knowledge of their students by involving potential student reactions, misconceptions, and questions in their Teaching Script.

Examples of KoCO

The next code relates to KoCO, which may include knowledge of state and local standards.[41] In terms of reflecting on their current curriculum, teachers were asked to share how their chosen topic ties into what they currently teach. For some teachers, they already teach this exact concept in their classroom ($N = 12$). For others, the concept fits into a unit that already exists in their curriculum ($N = 11$). The remainder mentioned that the topic does not tie into their current teaching, but relates to other courses, such as AP Chemistry, that they may teach in the future ($N = 2$).

After discussing how their concept ties into what they teach, teachers were asked to identify relevant standards. Some participants named NGSS standards ($N = 18$).[79] Based on their current teaching context, some teachers selected state-specific standards ($N = 9$). One teacher named AP Chemistry learning outcomes.[2]

The final component of the Teaching Script related to curriculum organization focuses on making decisions about what to teach. Participants were asked to share what students need to know about the concept they have chosen to teach. All teachers identified which aspects of the content were essential to student learning. This component of the Teaching Script potentially crosses over into KoG, specifically goals for student learning; however, the responses to this question align more with teachers' reasoning behind including this topic in their curriculum. A selection of responses is given below.

- "For this lesson, students need to know the subatomic particles, their characteristics and location in the atom, as well as knowledge of the arrangement of elements in the periodic table." – Teacher 15
- "Students need to be able to write out the set of quantum numbers for a given electron and be able to identify the element based on a given set of quantum numbers for a valence electron." – Teacher 28
- "They need to know the definition of the effective nuclear charge, and how it relates to how electrons fill into the orbitals." – Teacher 7

Summary of KoCO

About half of the participants currently teach their chosen topic whereas the other half used the Teaching Script to plan out how they would bring this topic into their instruction. Teachers identified relevant NGSS, state, or AP chemistry standards that would guide their teaching. Responses related to intended student learning outcomes were also coded as KoCO as these comments specifically identified what students should gain from this lesson. The main themes of KoCO were:

- Teachers were able to make informed decisions about what to teach for their chosen topic, meaning that they could adjust the level of content knowledge presented to students to meet intended learning outcomes.
- Teachers were aware of how their topic fit into the standards used in their school or department.

Participants demonstrated their knowledge of curriculum design and standards in relation to how they plan to bring their chosen concept into their instruction, thus showing their PCK.

Examples of KoT

The next code is KoT, which involves the discussion of teaching methods and activities.[41] Teachers were asked to share the teaching procedures related to their chosen lesson as well as their timeline for covering this concept. Each participant described teaching strategies that they would use for their topic. The majority of teachers chose to use multiple teaching approaches for their lesson. Many teachers felt that direct instruction was necessary to introduce this concept to their students ($N = 11$).

- "I would cover the material in a lecture format. Within the lecturing, I would cover example problems and explain the whole process is very detailed instructions." – Teacher 11
- "For this lesson I use direct instruction, I model the solution of problems and gradually release the responsibility of solving problems to my students." – Teacher 15

- “I would use a fair amount of direct instruction coupled with some introductory activities and a lot of varied practice at different levels of difficulty and scaffolding.” – Teacher 2

Teachers also discussed using labs or demonstrations to learn about their chosen concept ($N = 5$).

- “I would have the students perform a lab that determines the density of water.” – Teacher 14
- “Students will circle to different lab stations to experiment with a set of ob-scertainers. Students will predict what is inside each ob-scertainer and answer questions relating this to how scientists were able to make discoveries about the atom even though they couldn’t see the atom itself.” – Teacher 4
- “Demonstration: I will heat a very small amount of solid menthol on a hot plate and ask students to record their observations.” – Teacher 12

Another teaching strategy discussed in the Teaching Script was the use of models ($N = 6$).

- “I think I would start with having students draw their own models of the atom, then give them a list of all the drawings of atoms models and see which one they most align with.” – Teacher 6
- “I would try to use models to help students visualize the shape of orbitals.” – Teacher 5
- “I like to use models, so I plan to use balloons as a model of the s + p orbitals.” – Teacher 20

Other teachers involved the use of practice problems as a means of student-focused learning ($N = 8$).

- “Understanding quantum numbers requires students to perform a large number of practice problems to be truly comfortable with them.” – Teacher 8
- “The students would then get additional practice in the form of a worksheet, and we would go over this in class so I could clear up any troubles the students were having with the material.” – Teacher 11

Often overlapping with the use of practice problems, several participants chose to utilize group work activities, including guided inquiry learning ($N = 7$).

- “For POGILs I use a catch and release model: students work through a specific set of questions and I set a timer. We return to a big group to discuss/go over answers and clear up any questions/misconceptions. At the end of the POGIL we always summarize our thinking and learning into one or two sentences based on what they learned.” – Teacher 16
- “Quantum Mechanical Model POGIL – students get into small groups and work together to get a simple understanding of the vocab that will be used and the allowed values each quantum number can have.” – Teacher 25
- “Students will pair with one other student and compare their initial model (hypothesis) to develop a working group model. Students will then refine model by going back to obscertainer for further testing…Students will draw their group model on the white board…Students will find a perspective match with another group and further refine model.” – Teacher 24

As a teaching method, and as a form of assessment, teachers used small and large group discussion as a means of identifying student misconceptions and allowing students to share their thoughts on the topic at hand. ($N = 4$).

- “Discussion protocol-inner/outer circle: I like this discussion technique because students get a chance to talk to a smaller group before sharing with a larger group. You have two prompts and one circle starts the discussion on one prompt and the other circle listens and shares then flip roles. This leads to a larger class discussion about each topic.” – Teacher 6
- “Have student groups discuss, practice, and then present these ideas to the class to get at their collective understanding of these topics.” – Teacher 3
- “We will complete the notes together, while I ask questions and lead the class discussion during the notes.” – Teacher 26

The final section of the Teaching Script relating to teaching procedures relates to how the teachers would address and correct misconceptions held by students ($N = 19$). A selection of responses is given below.

- “I plan to use lecture, videos to show visually what is happening, and many examples to help clear the misconceptions.” – Teacher 21
- “I tell them to use the values that each quantum number *can* have, rather than rely on the periodic table.” – Teacher 25
- “These misconceptions are often addressed through sheer practice and reviewing of notes.” – Teacher 8
- “I think the best way is to show this image or model and then very clearly state that this model is wrong and to make a big point of it.” – Teacher 23

<u>Summary of KoT</u>

A majority of the participants chose to use multiple teaching methods when carrying out the lesson they designed for the Teaching Script. Some teachers outlined exactly what they would do throughout the lesson, while others described why they chose specific methods to teach their topic. Many of the teachers addressed misconceptions through the teaching procedures that they selected for this lesson. The most common themes for KoT were:

- Teachers most commonly chose to cover material through direct instruction and group practice problems.
- That teachers employed a variety of teaching strategies when designing a lesson for their chosen topic, revealing a desire to differentiate instruction.

Examples of KoA

For the Teaching Script assignment, participants were not explicitly asked to detail their assessment methods for this lesson. However, many shared formal and informal assessments they plan to use while discussing teaching procedures, which demonstrates their KoA.[41] Like with the CoRe, some assessment methods appeared in participants' discussion of teaching strategies.

- "Assessment: Students will revise their models, then draw a model of how we can smell that someone burned popcorn from a long distance away without seeing any burned popcorn for themselves." – Teacher 12
- "I start each class period with a 2 to 20 question long formative assignment as a bellringer. When introducing a new concept, I'll generally ask one or two open ended questions to see what students already know about that topic. I will also add a few multiple choice questions from topics we've already covered as a review." – Teacher 26
- "'First to 5'– A formative assessment." – Teacher 9

As shown above in the KoT section, some teachers would use discussion techniques as a form of assessment for their chosen lesson (*N* = 4).

Below is one example of a teacher mentioning assessment without providing details for how they would assess student learning.

- "This topic will take a class period for lecture and a class period for review and assessment." – Teacher 21

<u>Summary of KoA</u>

In the Teaching Script, assessment methods appeared in the teaching strategies section and teachers identified methods that could be used for assessment. Teachers also mentioned the need for assessment without providing specific details for how they would carry this out. It is important to note that some teachers included what are assessment methods in their Teaching Script but did not clearly identify them as forms of assessment. In analyzing their PCK, it is crucial to understand whether teachers actively possess KoA or if they are simply using these methods without acknowledging their purpose. Only 69.2% of participants clearly demonstrated their KoA. The main theme that emerged from teachers' KoA was:

- Many teachers identified assessment methods in the teaching procedures section of the Teaching Script table, but some teachers did not directly identify how they would like to assess students.

KoA was the least frequent code for the Teaching Script data, thus highlighting a gap either in the design for the Teaching Script module or in teachers' ability to plan appropriate assessments.

Examples of KoR

The final code in Codebook 2 discusses KoR.[41] In the Teaching Script assignment, teachers were asked to identify materials that they would provide to students who wanted to learn more about their topic. The majority of teachers chose to provide videos ($N = 18$) or reading materials ($N = 14$), many of whom provided links to specific resources. Others chose to allow for inquiry, through labs, demonstrations, or activities ($N = 5$). A couple of the teachers chose to provide models, including simulations, to support student curiosity ($N = 2$). One teacher discussed having one-on-one interactions with the students to answer questions or provide more depth to a concept. One teacher also mentioned an outreach opportunity by having a scientist interact with the class through video conferencing or in-person presentations.

Summary of KoR

Teachers identified specific resources that they would provide to students for further learning, including videos, readings, or additional classroom activities, such as labs, simulations, or demonstrations. One teacher discussed inviting a scientist to interact with their students through outreach. Participants demonstrated their knowledge of specific resources that they could utilize to bolster student learning or provide additional information for the more curious. The main theme for KoR was:

- Teachers were able to identify and provide resources to support further learning for curious students, with most providing videos or reading materials.

Summary of Teaching Script Data

The Teaching Script allowed participants to prepare a lesson on a challenging topic related to CHEM 770 concepts. Teachers provided good detail regarding their content knowledge (KoSc), as well as why and how they plan to bring these topics into their classrooms. By combining their KoSc, KoCO, and KoT, participants demonstrated improvements to their PCK quality. This module encouraged teachers to anticipate student reactions and misconceptions and prompted teachers to plan out teaching procedures, assessment methods, and additional resources in advance. Many teachers possessed all knowledge bases that comprise PCK. The main themes that appeared in the Teaching Script were:

- Teachers were able to design a lesson for a challenging topic involving diverse teaching strategies. By combining their KoSc and KoT, teachers demonstrated improved PCK quality.
- Most teachers were able to provide real-world examples for their topic to support student learning; however, some participants stated that real-world were impossible to find for their topic, potentially implying a lack of investigation or interest. Thus, most participants demonstrated their KoG in combination with their KoSt, which indicated improved PCK quality. This also indicates that the participants that did not include real-world connections may possess a gap in their KoG as a component of their PCK.
- Participants were able to express motivations for student learning by demonstrating an understanding of students' prior knowledge and interests. Thus, participants demonstrated their KoSt as a component of their PCK.

Module Survey – Teaching Script

After completing the Teaching Script assignment, teachers were invited to complete a survey about their experience creating a Teaching Script for their topic.

Twenty-four participants completed the Teaching Script module survey in Fall 2021. In the survey, participants were asked if they would feel comfortable teaching their chosen topic without preparation. Of the 24 teachers, 10 (41.7%) would not feel comfortable, 9 (37.5%) would feel comfortable, and 5 (20.8%) would feel comfortable teaching without preparing beforehand but did not think it was the best way to teach. When asked about their confidence level on a scale of 1 to 6 for teaching their concept, the average confidence score was 5.08. Upon creating a Teaching Script for their topic, 11 teachers (45.8%) did not find it challenging and 13 (54.2%) did find it challenging, with 3 of these teachers finding only some aspects to be challenging. The Teaching Script module survey was coded using Codebooks 1 and 4.

Codebook 1

Coding frequencies for Codebook 1 are given in Table 160.

Table 160. Module Survey Coding Frequencies for Semester 1 Teaching Script – CB1

Code	**Abbreviation**	**Total Number of Teachers Represented (*N* = 24)**	**Percentage of Total Responses (%)**
Attitudes	A-p	2	8.3
	A-c	13	54.2
Knowledge	K-p	1	4.2
	K-c	17	70.8
Background	B	2	8.3

Teaching	T	23	95.8
Feedback	F	8	33.3
Modules	M	20	83.3
Interaction	I	3	12.5
Reflection	R	13	54.2

Examples of Attitudes (A-p and A-c)

Two teachers shared attitudes they had before entering the program, including finding their atomic theory topic "quite uninteresting when [they] learned about it in college" (Teacher 8) and feeling "okay about just telling students something and then having them regurgitate it to demonstrate their understanding" (Teacher 12). Teacher 12 also shared current attitudes that they "really feel like [they] need to be making more of an effort to get students to come to the information themselves."

Upon sharing current attitudes, many teachers (*N* = 10) discussed gains in confidence in their content knowledge because of the CHEM 770 course and completing the Teaching Script assignment.

- "The course has helped my understanding of topics at a much higher level of what I teach and I think this gives me confidence as a teacher and helps me help students better." – Teacher 15
- "The content in the course has given me confidence in using the equation to perform calculations." – Teacher 22
- "Thinking this topic through as thoroughly as I have done here has definitely increased my confidence." – Teacher 26

- “I felt pretty good about this topic, but now I feel as though I have a renewed confidence in teaching it” – Teacher 11

One teacher discussed having fun completing the Teaching Script module.

- “With the knowledge that I had it was more fun than challenging or stressful to lay out this script. I had fun with it.” – Teacher 3

One teacher discussed how their attitudes toward teaching this topic could be improved with a stronger understanding of the content’s applications.

- “I think if I understood how quantum numbers are used on a macroscopic level, I would have more enthusiasm for teaching this concept.” – Teacher 25

One teacher shared negative attitudes that they held while participating in the MS program. It is unclear if this lack of confidence is due to the program itself or their experience in their own classroom.

- “I want to make sure I am teaching the best I can, and this semester is making me feel like a failure. I have lost my self-confidence.” – Teacher 7

<u>Summary of Attitudes (A-p and A-c)</u>

In the Teaching Script survey, teachers discussed gaining more confidence in their content knowledge, as well as their teaching of chemistry content, due to the CHEM 770 course. One teacher also shared feeling like they had lost confidence, however it was unclear if this change resulted from their experience in the program. The main theme for teacher attitudes was:

- That teachers gained confidence in their content understanding by taking CHEM 770 and completing the Teaching Script assignment.

Examples of Knowledge (K-p and K-c)

One teacher discussed changes in their content knowledge prior to and after taking the CHEM 770 course.

- Teacher 9:
  - Prior: "I needed a brush up on all this content."
  - Current: "Instructor A's excellent explanations at the whiteboard during the video lesson really helped me visualize the subshells and eventually how this is connected to the LCAO MO model and VSEPR model."

Many of the teacher ($N = 17$, 70.3%) discussed their current knowledge after participating in the CHEM 770 course. A selection of responses is given below.

- "This module forced me to really sit with the scientists and their experiments and put into words how each scientist came to their conclusions. I think in the process I gained an even better understanding of the evidence." – Teacher 4
- "I was not very confident in the mathematics of the quantum mechanical model but after taking this class I feel much more confident in some of the "non-calculus" aspects of the mathematical concepts." – Teacher 24
- "The content of the course has greatly increased my understanding of bonding and atomic theory in general." – Teacher 26

Summary of Knowledge (K-p and K-c)

Many participants discussed specific areas of improvement to their content knowledge after participating in CHEM 770. Improvement to their KoSc indicates improvement to their overall PCK. Participants attributed their improved content knowledge to the instruction they have received in the MS program as well as through their own work in the course. The most common theme for teachers' knowledge was:

- The course content for CHEM 770 helped teachers gain a stronger understanding of atomic theory topics.

<u>Background</u>

Through the module survey, two teachers shared information about their backgrounds.

- "I began teaching Chemistry in 2014, after taking my last Chemistry course in 1989 at [university]." – Teacher 9
- "When I first started teaching, my teacher education program had us write lesson plans for everything that we planned on doing." – Teacher 12

<u>Examples of Teaching</u>

Eighteen teachers (75%) shared how their completion of the Teaching Script assignment transformed their teaching of a CHEM 770 topic. Several teachers discussed how they hope to improve their teaching in the future for their students. A selection of responses is given below.

- "It has helped me in my understanding and planning on teaching a different way than I have before on this topic. I think this way will be better and my students will understand this topic more." – Teacher 21
- "First, it helped me to highlight where I can improve as a teaching to become more effective and efficient for my students. Second, it has shown me where my own material may be lacking, and how I can update it in order to make it more relevant to my students." – Teacher 11

- "I think I definitely put a lot more thought into trying to make electron configurations more accessible to my students and providing relevance to the real world in a way that would make learning about them more interesting." – Teacher 16

Other teachers mentioned how the course content and Teaching Script inspired them to bring their topic into their instruction.

- "Transformed in the sense of teaching it at all, which I would not have done without learning about this material in this course." – Teacher 3
- "This module has led me to consider teaching this topic. As stated before the past 5 years it has not been touched in any science classes." – Teacher 6

Summary of Teaching

Many teachers shared how they have placed more effort and motivation toward teaching chemistry content more effectively after participating in CHEM 770, specifically through their development of a Teaching Script. The main themes for teaching were:

- The Teaching Script allowed teachers to reflect on their current teaching methods for their topic and plan changes for future instruction.
- The CHEM 770 course and module assignment inspired teachers to emphasize new topics in their instruction.

Teachers' comments demonstrated their KoCO and KoT, indicating improved PCK.

Feedback

Data coded as feedback was sent directly to MS program instructors.

<u>Examples of Modules</u>

The participants were asked to explain whether it was challenging to create a Teaching Script for their chosen concept. Multiple teachers mentioned the challenge of anticipating student reactions, including finding the exercise to be inauthentic.

- "I found it really tedious to write out a fake conversation between me and my students. It felt forced and not at all like the conversations I usually have with students..." – Teacher 28
- "The hard part is coming up with the student response. I had to think how my students might word the response or what questions they might ask." – Teacher 14
- "It was challenging for me to write how I would teach this without knowing how my students will respond to the content." – Teacher 26

Some teachers also discussed the difficulty associated with writing out a script of their teaching verbatim.

- "Writing down word for word what I was going to say. I like to improvise so it was hard writing down everything." – Teacher 21
- "It was hard to write down what I would say." – Teacher 20
- "Not challenging, just awkward because I don't ever really write down what I will say to my classes. I really let my students drive our instruction and that makes it difficult to know exactly what I would say ahead of time." – Teacher 16

Others found this aspect of the assignment to be less challenging.

- "It was not all that challenging creating a script for this concept. For the most part I imagined how I would teach this concept in front of a class and wrote that down. It felt natural." – Teacher 32

- "I found myself talking out loud as if I was in class presenting it to my students and typing what I would say." – Teacher 14

Summary of Modules

Several participants expressed challenging aspects of the Teaching Script, particularly highlighting the difficulty of scripting their instruction verbatim. Some teachers specifically identified the challenge of anticipating their students' response to their instruction. Others found it easier to script out their teaching as if they were in the process of presenting the content to their students. The most common theme for the modules code was:

- Teachers found it difficult to create a scripted plan of their instruction, especially in relation to student responses.

Although teachers identified this aspect as being most challenging, it does not indicate a lack of KoSt. The Teaching Script required teachers to view their instruction from a new perspective and many found this to be challenging.

Interaction

Two teachers discussed interactions in their Teaching Script survey related to how they could improve their teaching confidence.

- "Watching some sample lessons online. I would really like to observe this unit or see a sample entire unit laid out. I got a decent idea from the discussion forums, but it would really help me see where and how to do things if I could see someone's plans/videos." – Teacher 6

- "I would feel more comfortable getting feedback from other teachers. Do they think this sequence is a good idea? Am I missing anything? Will this create or reinforce any student misconceptions?" – Teacher 12

Another teacher found it useful to read the Teaching Script discussion forums to learn about more ideas for teaching atomic theory topics.

- "It gave me opportunity to explore the options on how I can teach the concept by reading discussion posts from my classmates." – Teacher 29

All three teachers found that interactions with other teachers would benefit their teaching in the future.

Reflection

Over half of the teachers reflected on their experience completing the Teaching Script module in terms of their teaching and learning. Some examples of reflective thoughts are given below.

- "This module forced me to really sit with the scientists and their experiments and put into words how each scientist came to their conclusions." – Teacher 4
- "I think that for a lot of the concepts I teach I do not necessary ponder about extensions for every lesson, or misconceptions/most likely asked questions. However, this is something I should consider when making a lesson plan. That way I can be more prepared when teaching and anticipate more for my specific lessons." – Teacher 7
- "I don't operate in a structured, scripted way in most of the things I teach, particularly after having taught chemistry for so many years. It all becomes rather second nature and it's easy to slip into a degree of routine and just sort of picking

up where we left off from day to day and rely on the memories of what has and has not worked over the years." – Teacher 2

Codebook 4

Codebook 4 allowed for a breakdown of teacher statements by source of motivation. Each comment was analyzed to determine its focus, either on the participant's learning, their students' learning, or the participant's teaching. Coding frequencies are displayed in Table 161.

Table 161. Module Survey Coding Frequencies for Semester 1 Teaching Script – CB4

Code	**Abbreviation**	**Total Number of Teachers Represented (*N* = 24)**	**Percentage of Total Responses (%)**
Learning-focused	L-f	20	83.3
Student-focused	S-f	17	70.8
Teaching-focused	T-f	24	100

Most of the teachers (70.8%) demonstrated all three motivations in their Teaching Script survey statements. All teachers ($N = 24$) shared teaching-focused comments. A selection of responses is given below.

- "I fully rewrote my materials based on this course, shifted the focus from scientists and conclusions to experiments and evidence." – Teacher 4

- "It gave me opportunity to explore the options on how I can teach the concept by reading discussion posts from my classmates." – Teacher 29
- "This course gave me a much better idea for what kinds of questions are good/common to be asked about quantum numbers. They aren't tested in the AP curriculum, and although they required for the concurrent enrollment class I teach they have been glossed over on the final, so I haven't had a good basis for how to formulate my questions regarding this topic." – Teacher 28

Most participants (*N* = 20, 83.3%) gave statements in the survey focused on their own learning. Some examples are given below.

- "The findings from Planck, Heisenberg, and Schrödinger helped me add more historical context behind quantum numbers." – Teacher 25
- "The content of this course made me understand quantum numbers much better than I did in college the first time around. I still confuse the terminology such as subshells, orbitals, and shells." – Teacher 8
- "I have gained more confidence in my content knowledge." – Teacher 15

Most participants (*N* = 17, 70.8%) also discussed student-focused motivations related to their experience creating a Teaching Script. Examples of student-focused statements are shown below.

- "With the pendulum swinging to more student-centered learning, this activity puts most of the ownership on the students. Also, because the students have an emotional response (frustration) to the activity, it acts as an anchor point for future learning goals." – Teacher 24

- “Prior to the course, I felt okay about just telling students something and then having them regurgitate it to demonstrate their understanding. Now, I really feel like I need to be making more of an effort to get students to come to the information themselves by crafting lessons that allow students to form these mental models.” – Teacher 12
- “It challenged me to dig deeper and to challenge my students with higher level chemistry because it will help them should they ever take a chemistry class in college.” – Teacher 21

Summary of Module Survey – Teaching Script

Ten of the twenty-four teachers shared gains in confidence in their content knowledge due to the CHEM 770 course, demonstrating improved KoSc as a component of their PCK. Most teachers (70.3%) discussed increased content knowledge as a result of the course. By completing the Teaching Script assignment, 75% of the participants stated that their teaching had been transformed by completing the module and CHEM 770 course, through improving their instruction for their students and bringing atomic theory topics into their teaching. By combining their KoSt, KoSc, and KoT, participants demonstrated improved PCK quality through their Teaching Scripts. Many teachers found it challenging to script out a teaching scenario. Some teachers found it to be a useful, “natural” exercise, while others found it to be “tedious” or “awkward.” In the survey, three teachers discussed the benefit of interacting with other teachers to get feedback on their own teaching. Thus, interactions with other MS program participants supported teachers’ PCK and professional development. Participants reflected on their experience with the module, stating that the assignment gave them the opportunity to think extensively about how they would bring new content and pedagogical knowledge into their lessons. Combining their KoSc and KoT indicated higher quality PCK. The most common themes from the Teaching Script module survey were:

- Teachers were able to apply new content knowledge learned in CHEM 770 with confidence. By improving their KoSc, teachers improved their overall PCK and teaching effectiveness.
- The Teaching Script itself inspired teachers to plan a lesson for a new topic, bring new content into their teaching, and reflect on potential student misconceptions. This elaboration on their KoSc, KoT, and KoSt demonstrated improvements to the quantity and quality of their PCK.
- Teachers had split opinions on the utility of creating a script of their instruction with student interactions.

In the Teaching Script survey, all teachers shared teaching-focused motivations related to their completion of the module assignment. Most of the participants ($N = 20$, 83.3%) discussed learning focused motivations for their gain of content knowledge through the CHEM 770 course, while 70.8% of the participants shared their motivations for future teaching and learning related to their own students.

End-of-Semester Survey

At the end of the Fall 2021 semester, I sent out an email invitation to participants of CHEM 770 and CHEM 771 to complete a survey about their experiences in content courses, and the program overall, during the given semester. Responses to this survey were coded with Codebooks 1 and 4 ($N = 27$).

Codebook 1

Coding frequencies for Codebook 1can be found in Table 162.

Table 162. End-of-Semester Survey Coding Frequencies for Semester 1 – CB1

Code	**Abbreviation**	**Total Number of Teachers Represented (N = 27)**	**Percentage of Total Responses (%)**
Attitudes	A-c	19	70.4
Knowledge	K-p	1	3.7
	K-c	27	100
Skill	S-p	1	3.7
	S-c	16	59.2
Teaching	T	17	63.0
Feedback	F	27	100
Modules	M	13	48.1
Interaction	I	20	74.1
Reflection	R	18	66.7

Examples of Attitudes (A-c)

Teachers' current attitudes included positive feelings related to applying new knowledge gained through the program.

- "These courses allowed me to grow as an educator, and I am excited to use what I have learned in my class" – Teacher 11

Participants also indicated increased confidence in their content knowledge and ability to teach concepts covered in CHEM 770 and CHEM 771.

- "My confidence solving chemistry problems has increased." – Teacher 9
- "I feel more confident as a teacher in IMF and atomic history." – Teacher 1
- "I feel so much more confident and prepared to teach the concepts that were part of these courses." – Teacher 2

One teacher also shared feelings about their level of content knowledge relative to other MS program participants.

- "I feel like I know less than others." – Teacher 23

Teachers also shared feelings of increased motivation or looking forward to future semesters in the MS program.

- This semester has "given me the drive and motivation to keep changing and bettering my teaching." – Teacher 7
- "I've rediscovered my love of being a learner myself, and of being challenged to learn hard things. That's a great fire to have back inside of myself professionally…Having a new fire as a learner makes me more excited to get back into class each day and week to try new things. That kind of energy is hard to replicate." – Teacher 2
- "My enthusiasm is contagious and this is sparking it again." – Teacher 27
- "I am excited to take more classes!" – Teacher 22

Summary of Attitudes (A-c)

Through the MS program, teachers gained confidence in their teaching of chemistry topics. Participants also mentioned increased motivation, enthusiasm, and excitement to teach and "try new things" that they have learned through the program itself or through interactions with classmates. One teacher shared feelings that they may "know less than others" in the course. The main themes for attitudes were:

- That the Fall 2021 semester courses gave teachers increased confidence in their ability to teach using new content knowledge.
- That teachers expressed positive feelings, such as increased enthusiasm and excitement, to continue in the MS program.

Examples of Knowledge (K-p and K-c)

One teacher discussed prior knowledge, noting that their "content knowledge needed brushing up." (Teacher 9). All participants gave statements related to their current level of knowledge after the Fall 2021 semester in the MS program. The majority of teachers (N = 24) explicitly expressed that their content knowledge increased as a result of their involvement in MS program courses. Participants first discussed how their content knowledge changed after participating in content courses.

- "I feel like [the Fall 2021 courses] really helped expand my prior knowledge (more than most core courses) and helped me grow as I teach these topics." – Teacher 10
- "The courses challenged me and helped me to see holes in my knowledge and elevated my content knowledge. Taking these courses later in my career helps me to see connections that I did not see when I was younger." – Teacher 9

- “I learned a tremendous amount of content in this course. The rigor of the course was challenging and covered a lot of material.” – Teacher 24
- “I feel that this course really challenged me and improved my understanding of atomic theory.” – Teacher 5

Teachers shared how improved content understanding impacts how well they can teach students.

- “The exposure to content at this level helps my understanding and enables me to teach students better.” – Teacher 15
- “Even though a lot of the content goes beyond what I teach in AP Chemistry or pre-AP chemistry, I have a much broader sense of the material and am able to answer higher level student questions a lot better... I have a better understanding of the content I teach and that allows me to focus more on teaching rather than trying to learn the content along with my students.”” – Teacher 16
- “I am a LOVER of hard new content and deepening my understanding so that I have a better foundation in the things that are behind the scenes of the things I absolutely must teach my students in any particular chemistry class.” – Teacher 2

Participants shared resources that they have gained through the MS program courses.

- “I got…from both classes a lot of good resources I will use in my classroom this year or next, or even have used it already.” – Teacher 7
- “My knowledge of intermolecular forces has been reinforced and I gained some more ideas about how to visualize VSEPR theory.” – Teacher 13
- “It has increased my content knowledge and given me plenty of ideas to try and implement throughout the rest the year and into my future.” – Teacher 11

Summary of Knowledge (K-p and K-c)

Through the Fall 2021 content courses, participants were able to deepen their chemistry content knowledge. Many teachers felt that their increased understanding will enable them to teach their students more effectively. Participants also discussed gaining resources and teaching methods through MS program courses. The main theme for knowledge was:

- That the Fall 2021 courses helped teachers identify gaps in their content knowledge and supported content and pedagogical knowledge gains.

Teachers gained KoSc, KoT, and KoR through MS program content courses, indicating improvements to their overall PCK.

Examples of Skill (S-p and S-c)

One teacher discussed their current level of skill, stating that they "just need to get better at balancing" as they progress through the program (Teacher 7). Over half of the teachers (59.2%) identified skills they have developed during their time in the program. Participants expressed that they are better able to answer student questions due to what they have learned in the core courses. Their pedagogical skill improved due to increased KoSc and KoT as components of their PCK.

- "Even though a lot of the content goes beyond what I teach in AP chemistry or pre-ap chemistry, I have a much broader sense of the material and am able to answer higher level student questions a lot better." – Teacher 16
- "I feel better equipped to explain content." – Teacher 12
- "I am much better at answering student questions that ask about why a certain chemistry concept is understood." – Teacher 19

- “I feel I have a deeper understanding and better ability to explain concepts to my students.” – Teacher 14

Some teachers mentioned specific changes in their pedagogical skill after the Fall 2021 semester, particularly relating to teaching procedures and curriculum organization. These improvements to their KoT and KoCO indicate improved PCK.

- “By having a greater understanding/practice in the content I'm better able to understand what to emphasize is important to my different content classes.” – Teacher 28
- “I am thinking more deeply about the most appropriate sequence of topics in my teaching and about how in depth to go with certain concepts.” – Teacher 17
- “I find myself asking more open-ended questions to my students and starting with problems and scenarios more than I used to.” – Teacher 14
- “Now that I'm able to see the connections between topics, it's been easier for me to tie in content from a previous chapter in the current one. It also helps to have relevant, real life examples of problems so students can practice their problem solving instead of just using random numbers and values.” – Teacher 25

Two teachers discussed gaining better time management skills through participation in CHEM 770.

- “I have gained time management skills. CHEM 770 was very intensive and had a lot of little assignments to complete. As a new teacher, I had to consciously carve out time to get my work done and take the time to meaningfully take in the information.” – Teacher 5
- “Appreciation for the need for time management!” – Teacher 28

<u>Summary of Skill (S-p and S-c)</u>

After the Fall 2021 semester, teachers identified skills they had developed through the MS program courses, such as an ability to explain the content more effectively, a deeper understanding of appropriate curriculum organization, and time management skills. The main themes for skill were:

- That teachers were better able to explain concepts to their students.
- That teachers were better able to organize content in their own classes after gaining a deeper content understanding in the MS program courses.

<u>Examples of Teaching</u>

The end-of-semester survey allowed teachers to reflect on how they have made changes to their teaching because of what they have learned through the MS program. Participants talked about how their instruction was impacted by what they had learned through MS program courses and how they plan to make changes in future semesters. They specifically discussed improvements to their KoCO, which demonstrated improved PCK.

- “I feel I have grown as a chemistry teacher and have taken notes on where to improve my class for next year based on what I have learned in these classes.” – Teacher 14
- “The courses have made me rethink my approach to how I was to present the information to the students, and what information is truly the most important. I want to teach them the information they will need to succeed after high school.” – Teacher 11

- “I wouldn't say much has changed in my classroom, mostly because by the time a topic was discussed, my calendar was already made and I couldn't change it too much. I do have a lot of activities and labs and ideas from the other teachers that I would like to eventually incorporate into my curriculum, but that's more of a next year thing.” – Teacher 25

Some participants also shared examples of changes they are currently enacting or observing in their own classrooms.

- “I feel better able to explain the content that was within the course. I feel like my students are thinking about things deeper as a result and are having more fruitful discussions.” – Teacher 12
- “I have become a more effective teacher this year by being able to show my students what I have been up to during my summertime. I have also become a more effective teacher this year by trying out new activities with students. Lastly, I have become a better teacher this year by eliminating some activities and replacing them with more effective ones.” – Teacher 13

Teachers discussed resources they have learned about or developed through the MS program courses.

- “I have new ‘assignments’ that I have created that will come in handy in the future.” – Teacher 9
- “All of the pedagogy assignments have given me so many additional activities I can do in class. I love having all the extra ideas that I can use and I really liked the outline/layout for lessons used in 771. I changed it a little to match my classroom.” – Teacher 16

- "I find that I am thinking more intentionally about how to present the content and what methods and resources to use to help my students understand the concepts. I also believe that I will make it a point to look at the literature (especially JChemEd) in the future when I am struggling with how to best present certain concepts to my students." – Teacher 17

Summary of Teaching

In this survey, teachers expressed a desire to reevaluate their teaching of CHEM 770 and CHEM 771 topics considering new content and teaching strategies they have learned through these courses. Some participants shared changes they have carried out in their own classrooms and others have identified resources they have developed or taken from MS program courses, fellow classmates, or from the literature to use in their own instruction. The main themes for teaching were:

- That teachers were able to reflect on their current teaching and think about how they would change their instruction in the future.
- That teachers gained resources through the MS program courses and interactions with other teachers in the program.

Feedback

All participants shared feedback on the Fall 2021 content courses. Data coded as feedback was sent directly to MS program instructors.

Examples of Modules

Although many of these comments were also coded as feedback, it was important for this project to better understand the impact and reception of the CoRe and Teaching

Script modules. Many participants identified these assignments as being meaningful to them as teachers.

- "I feel as a teacher, the teaching script [was] helpful because it gave various insight on topics and advice on how to address topics." – Teacher 14
- "I also enjoy assignments like the teaching script or the CoRe assignment because it forces you to create something new. Trying different activities in class and evaluating their effectiveness is good practice. These assignments are geared towards this idea." – Teacher 13
- "The teaching assignments (Pedagogy, CoRe, Script) help me to think about the content as a teacher." – Teacher 17
- "The 771 CoRe assignment was really only meaningful from the teacher perspective for me." – Teacher 19
- "As a teacher, I felt certain aspects such as the discussion boards, teaching script, and CoRe were meaningful to me because it helped me use the content in an educational way. I felt I was getting a lot of out of these assignments because they made me think about my classroom, my curriculum, and the strengths and weaknesses my students have with chemistry." – Teacher 25
- "The [Teaching] Script, also while it took more time than I hoped and I still am not comfortable writing dialogue as if a play it did help me to develop a better way of teaching a topic and really take time to absorb it and break it down to something that my students will hopefully understand." – Teacher 4

Other teachers felt that the modules were not meaningful and appeared to function as "busy work."

- “I personally think the Teaching Script could be replaced with another similar assignment that is more effective. What that would be I am not sure of however.” – Teacher 8
- “The CoRe and Teaching Script assignments really fall flat to me. Both feel like strategies I will never use in the future, and were only really there to add some points to the course.” – Teacher 10
- “I don't see the need or use of a Teaching Script in this career stage. I feel that a proper lesson plan is enough. Maybe this activity has not been appropriately sold, and it seems like a filler.” – Teacher 15
- “The CoRe and Teaching Script is a good idea but it was not helpful for my teaching it felt like busy work.” – Teacher 21
- “I also really don't like the formulaic nature of the Teaching Script assignment. I find it extraordinarily tedious to type out a script of a fake interaction between me and students.” – Teacher 28

Summary of Modules

Teachers shared their thoughts on the CoRe and Teaching Script module assignments. Some participants found these assignments useful for thinking about the content from a teaching perspective. Several teachers viewed these assignments as filler and did not find them to be meaningful from either a student or teacher perspective. The most common themes for the modules were:

- That the module assignments allowed teachers to reflect on the content through a teaching lens, which gave participants the opportunity to apply new knowledge directly to their instruction. Teachers practiced their PCK by combining their KoSc and KoT, which allowed them to develop higher quality PCK.

- That many teachers did not find the module assignments meaningful because they did not find the modules applicable to their teaching or learning.

Examples of Interaction

Many participants (*N* = 20, 74.1%) talked about interactions they have experienced through the course and the impact these encounters and relationships had on them professionally and personally. Several teachers discussed the value of being able to exchange ideas with others in the program. A selection of responses is given below.

- "Any time I can talk to others about topics that I know I can teach or see how other teach topics is very valuable to me." – Teacher 7
- "I enjoyed the discussion forums and being able to bounce ideas off of my classmates." – Teacher 21
- "It is nice to be able to talk to other teachers and share ideas in discussions, this stuff probably was more relevant to my own classes... Collaboration between peers has been very helpful for me and not something that I expected to have much of with an online class." – Teacher 4
- "As a teacher I most appreciated the opportunity to share teaching practices with other teachers." – Teacher 28

Participants also mentioned being able to build connections with other teachers and instructors for the MS program.

- "The CHEM 770…weekly Zoom meetings were the most meaningful to me because it helped make a connection between my peers and Instructor A." – Teacher 24
- "I value Instructor A's teaching and the ability to get to know other teachers across the United States. This is worth the money in my opinion." – Teacher 20
- "I feel that the community of the program has been fabulous. Granted, the study group was student-initiated, but I feel that the communication and collaboration throughout this course and my experience in the program has exceeded my expectations." – Teacher 5
- "I have made positive connections with other teacher across the U.S. This has been an unexpected benefit." – Teacher 9

Relating to this semester, one participant expressed disappointment at not forming connections with other teachers in the program. Although this participant expressed above that they value the ability to get to know other teachers in the program, this was not true for the Fall 2021 semester.

- "I haven't really felt much of a connection with other students this semester, which has kind of been a bummer." – Teacher 20

Two teachers also shared a specific benefit of getting to interact with other teachers through the MS program.

- "Discussing topics with other teachers has been amazing. I love how everyone shares what they do for a topic and their difficulties. It helps me not feel like a complete failure when I read that another teacher has the same problem as me." – Teacher 25

- "I think sometimes having the realization that other people struggle with similar situations in the classroom. Bouncing ideas off of each other as a collective group is helpful and supportive." – Teacher 24

Summary of Interaction

A meaningful aspect of the MS program for the teachers involved is the connections they form with other teachers and the MS program instructors. Participants discussed gaining new KoSc and KoT, as well as forming relationships with other teachers in the program. Teachers gained knowledge and resources through their interactions with each other, demonstrating improvements to their PCK through collaboration. Teachers expressed that they feel a sense of community and support among other MS program participants. The most common theme for interaction was:

- The teachers found value in forming relationships with other teachers with whom they could exchange ideas and commiserate about teaching challenges.

Teachers emphasized the meaning they found in being able to interact with chemistry teachers around the country, thus demonstrating the value of this aspect of the MS program.

Reflection

The end-of-semester survey allowed participants to reflect on their Fall 2021 experience in the program overall. A selection of reflective statements is given below.

- "In my opinion, the better I understand chemistry content, the better I am able to help my students." – Teacher 13
- "The process of reflecting on the resources provided, the discussions on the boards, and my own teaching strategies have combined to give me a lot better

habit already of evaluating the activities, labs, demos, etc., that I use in my classroom." – Teacher 2

Some teachers reflected on how participating in the MS program has impacted their teaching effectiveness in relation to their own students.

- "My students appreciate that I can empathize with them because I am a student as well. I think viewing my course through the eyes of a student increases my effectiveness as a teacher." – Teacher 12
- "When I am learning and a student, I am more aware of the process of learning by my students and empathetic to the trials of learning new things." – Teacher 9
- "I think I am more aware and thoughtful of how I design a lesson and the questions I am presenting my students with." – Teacher 14
- "Better content knowledge for me means better understanding for my students. Discussions and application questions help me reach more kids and help more to make connections." – Teacher 27

Teachers discussed becoming more empathetic to the student experience after returning to their own role as a student in the MS program.

Codebook 4

Codebook 4 was used to analyze participants' motivations for statements made in the end-of-semester survey. Coding frequencies can be found in Table 163.

Table 163. End-of-Semester Survey Coding Frequencies for Semester 1 – CB4

Code	**Abbreviation**	**Total Number of Teachers Represented (N = 27)**	**Percentage of Total Responses (%)**
Learning-focused	L-f	27	100
Student-focused	S-f	14	51.9
Teaching-focused	T-f	27	100

All teachers described motivations focused on teaching or learning. About half of the participants (51.9%) shared student-focused statements. When reflecting on their experience in the MS program over the Fall 2021 semester, all participants shared sources of motivation related to teaching. Some examples are given below.

- "The one part about the summaries I liked is when we had to talk about how we would use the ideas in our class. That made me think about how I could be a more effective teacher." – Teacher 11
- "I feel I have grown as a chemistry teacher and have taken notes on where to improve my class for next year based on what I have learned in these classes." – Teacher 14
- "I think having a deeper knowledge on this topic will help me as a teacher." – Teacher 26

Each of the participants also shared statements focused on their own learning. A selection of responses is shown below.

- "Words of affirmation and constructive criticism are important to me and my learning." – Teacher 9
- "I feel that this course really challenged me and improved my understanding of atomic theory." – Teacher 5
- "I learned a tremendous amount of content in this course." – Teacher 24

The final code related to student-focused motivations. Over half of the participants (51.9%) shared statements of motivations to make changes in the future to benefit their students. Some examples are given below.

- "The courses have made me rethink my approach to how I was to present the information to the students, and what information is truly the most important. I want to teach them the information they will need to succeed after high school." – Teacher 11
- "When I am learning and a student, I am more aware of the process of learning by my students and empathetic to the trials of learning new things." – Teacher 9
- "It also helps to have relevant, real-life examples of problems so students can practice their problem solving instead of just using random numbers and values." – Teacher 25
- "Better content knowledge for me means better understanding for my students. Discussions and application questions help me reach more kids and help more to make connections." – Teacher 27

Summary of End-of-Semester Survey

The end-of-semester survey allowed twenty-seven teachers to reflect on their overall experience in the MS program for the Fall 2021 semester. Most of the teachers (70.4%) shared their current attitudes, including increased teaching confidence and motivation to improve their teaching in the future. One teacher felt that they "know less than others" in the course, thus potentially impacting their attitudes toward the program. Most participants ($N = 24$) explicitly stated that they have experienced increases in their chemistry content knowledge after participating in MS program courses. By increasing their KoSc, teachers experienced improvements to their overall PCK. Teachers also felt that they were better equipped to explain content and that they felt improvements to their pedagogical skill. Participants shared how they have altered, or planned to alter, their instruction based on ideas they have taken from the courses or peers. All participants interacted with the module assignments in both CHEM 770 and 771, with varying opinions on whether these modules were meaningful for reflecting on teaching or learning chemistry content. Interpersonal interactions were valuable to the teachers in the MS program and created a sense of community, even in the online format. These interactions supported teachers' PCK and professional development. The participants also reflected on what they have learned in the courses and how this has positively impacted their teaching effectiveness. All teachers shared teaching- and student-focused statements related to their experience in the MS program in Fall 2021. Many of the teachers (51.5%) also expressed student-focused statements. Teachers improved their overall PCK by developing stronger KoSc, KoCO, KoT, and KoR. The most common themes from the end-of-semester survey were:

- The interactive, albeit online, nature of the MS program allowed geographically diverse teachers to create a professional support network. These interactions supported participants' PCK and professional development.
- The MS content courses allowed teachers to deepen their content knowledge and experience more confidence in their ability to explain content. By improving and combining their KoSc and KoT, teachers experienced improved PCK quality.
- All teachers possessed motivations focused on their teaching and students, highlighting the desire of MS program participants to gain new knowledge and skills that would directly benefit their students and their professional expertise.

Summary of Semester 1

During Semester 1 of data collection, methods included CHEM 770 discussion forums, the CoRe module and its survey, the Teaching Script module and its survey, and the end-of-semester survey. The main themes for Semester 1 were:

- Interacting with other teachers in the MS program, particularly through discussion forums, elicited positive attitudes and motivation toward teaching chemistry due to the formation of a professional support network. The discussions also allowed teachers to exchange knowledge and ideas, which improved teachers' PCK through increased KoSc, KoT, and KoR. Teachers also improved their KoCO as a component of their PCK by making decisions about what new content to bring into their courses.
- Through the CoRe and Teaching Script modules, teachers demonstrated their PCK related to intermolecular interactions and atomic theory. By completing the modules, teachers revealed the presence and quantity of their PCK. By combining

PCK bases and reflecting on their teaching decisions, teachers demonstrated improvements to their PCK quality.

- Through the modules, teachers reflected on their current instruction of CHEM 770 and CHEM 771 topics and applied new knowledge gained in the MS program (KoSc). By combining their KoSc and KoT, teachers indicated improved PCK quality resulting from their participation in MS program courses. The modules also exposed gaps in participants' KoSc and KoT, which enabled them to make goals and action plans for their future teaching.
- The modules enabled teachers to approach their instruction from their students' perspective (KoSt). Although some teachers did not find it useful to create a script of their teaching, the process of thinking about potential student reactions and misconceptions allowed teachers to practice their KoSt and improve their instruction for their students. By combining their KoSt and KoT, teachers demonstrated improved PCK quality.
- Teachers gained chemistry content knowledge (KoSc) through the CHEM 770 and CHEM 771 courses which allowed them to improve their pedagogical skill and overall teaching effectiveness. Improved KoSc led to improved confidence in their overall PCK. This intertwining of their KoSc and KoT demonstrated improved PCK quality.
- The discussion forum threads, module surveys, and end-of-semester survey allowed teachers to share comments motivated by their teaching, their own learning, and implications for their students' learning. All teachers shared teaching-focused motivations for each method, demonstrating teachers'

application of MS program experiences to their teaching. Participants also reflected on learning that took place in the MS program, as well as how their experience would impact students' learning. These results indicate teachers' intentions to apply knowledge and skills gained in the MS program to their teaching, with the hopes to positively impact student learning.

Semester 2

During Semester 2, teachers were able to participate in one chemistry content course, CHEM 772, which focused on thermodynamics topics. A pedagogical course, CHEM 778, was also available for MS program participants, which focused on chemistry teaching strategies. These courses were fully online and primarily asynchronous. Optional weekly Zoom sessions were the only synchronous components of the courses. The data for Semester 2 is presented chronologically. The Midway Course Reflection was prompted halfway through the semester in CHEM 778 to learn about impacts to teachers' pedagogy. The CoRe and Teaching Script assignments were both due near the end of the semester, along with their associated module surveys. The end-of-semester survey was sent out after the conclusion of the semester. Table 164 discusses the methods used during Semester 2.

Table 164. Semester 2 Data Collection Methods

Term	**Data Collection Methods**	**ID Codes**
Semester 2	**CHEM 772:** CoRe Module Survey	 CoRe MS

	Teaching Script Module Survey	TS MS
	CHEM 778: Midway Course Reflection	 MCR
	General: End-of-Semester Survey	 EOS

CoRe

In Spring 2022, the CoRe was administered in the first half of CHEM 772: Thermodynamics. The CoRe was analyzed using Codebook 2 to assess participants' PCK. Table 165 displays the codes from Codebook 2 that appeared in the Semester 2 CoRe.

Table 165. CoRe Coding Frequencies for Semester 2 – CB2

Code	Abbreviation	Total Number of Teachers Represented (*N* = 18)	Percentage of Total Responses (%)
Knowledge of science	KoSc	18	100
Knowledge of goals	KoG	18	100
Knowledge of students	KoSt	18	100

Knowledge of curriculum organization	KoCO	18	100
Knowledge of teaching	KoT	18	100
Knowledge of assessment	KoA	18	100
Knowledge of resources	KoR	6	33.3

The CoRe assignment was created to gain information about participants' PCK, so it is not surprising that most codes were present in each of the responses. As mentioned in the literature review chapter, researchers have been encouraged to investigate the quality of PCK, not only its existence or quantity.[43] Based on the design of the module, all participants should be able to demonstrate PCK, which was true for the Semester 1 CoRe.

Examples of KoSc

The first component of PCK represented in the CoRe is KoSc, which includes science content, scientific practice, the nature of science, and scientific progress.[41] Participants identified a challenging topic related to thermodynamics topics. The most chosen topics were state functions (N = 10) and sign conventions/thermodynamics terminology (N = 6). Two teachers chose topics related to calorimetry (N = 2). Some teachers found these topics challenging to teach because of their students' struggles with the emphasis on both mathematical and conceptual relationships.

- "I can't tell you how many times I have had students this year who are struggling with chemistry tell me that they get the math but not the concepts behind the math. They can do the math problems but have no idea what the numbers mean or how it connects to the bigger picture." – Teacher 7

- "I think this is most challenging because it involves a high level of abstract thinking. Most of the changes are physical but many students can't picture the work and energy flow." – Teacher 6

Teachers discussed gaps in students' prior knowledge as posing challenges when teaching thermodynamics as well.

- "The concept of energy transformation and the physics behind it is difficult because many students take chemistry prior to taking physics and may not have learned enough about the topic in an 8th or 9th grade physical science class." – Teacher 18
- "This concept requires a background in Lewis structures and math, which can be challenging for some students especially if they struggled in or forgot about Lewis structures." – Teacher 25

Teachers also mentioned struggles with teaching these concepts due to their own challenges with understanding the content or a lack of experience.

- "I also struggle with these concepts, which makes it even more difficult to teach these concepts to my students." – Teacher 31
- "I see this as a reasonably challenging topic for me to teach largely because I haven't covered it at all extensively in the past with students." – Teacher 2

Participants then shared intentions for student learning, which included learning outcomes for their chosen topics. Some examples are given below.

- “Students must be able to determine if the system is performing work or if work is being done on the system.” – Teacher 33
- “I want the students to be able to identify the difference between system and surroundings.” – Teacher 6
- “My goal for the students would be able to go through calculations and explain why the answer is endothermic or exothermic.” – Teacher 14

After discussing student learning outcomes, teachers then shared what additional knowledge they possessed beyond what they would teach to their students. A selection of responses is given below.

- “I don’t expect my students to learn about adiabatic or isothermal processes. However, they may encounter scenarios that are adiabatic or isothermal in practice problems, they just aren’t labeled as such.” – Teacher 19
- “Understanding the degrees of freedom of motion for monatomic, diatomic, and polyatomic molecules and how the equipartition theorem is used to incorporate that into the internal energy of a system.” – Teacher 17
- “Internal energy and heat capacities are a function of not just the kinetic motion of the molecules, but also the potential energy stored in bonds from a translational, rotational, and vibrational standpoint.” – Teacher 30

The final prompting question related to KoSc asked teachers to discuss difficulties or limitations associated with the content. Again, teachers discussed the challenges posed by students’ prior knowledge.

- “Students will come into my class with different levels of science background which will be a difficulty.” – Teacher 23

- "There is a lot of physics involved in understanding thermodynamics in chemical reactions. Many students don't have that background when they take a chemistry class and some will once taking AP Chemistry." – Teacher 18

Participants also discussed challenges related to the abstract nature of thermodynamics topics.

- "The difficulties connected with teaching about heat, work, and internal energy are that they can be very abstract…Many of the situations presented in teaching this content can be very simple on the surface, but very complicated when looking at what is actually going on at a microscopic level." – Teacher 17
- "We are visualizing and modeling ideas with this topic that are abstract, like most things in chemistry, in that they both cannot be seen ever, and they are very small and interacting with large numbers of each other. The vibrational ideas are verifiable through proxy in things like NMR and other instrumentation, but even I do not have a solid grasp of these concepts both in terms of which processes give this information and how to relate data to models and understandings that the chemistry community has." – Teacher 3
- "It can be difficult to visualize what is happening when work is being done on a system or when work is being done by a system. It can also be difficult to visualize what is happening in the system itself when heat is added or removed." – Teacher 31

Some teachers mentioned difficulties with the labs used to teach thermodynamics concepts, either related to the experiment itself or student understanding.

- "They may also not like doing exploratory based labs I know my students struggle with thinking on their own and just asking me to tell them the answers. I think this might also be a limitation because again they cannot fall back on math. I noticed these types of labs even with my honor students tend to be the thing the struggle with the most." – Teacher 7
- "I think that the largest limitation with this idea is the difficulty in doing real-world experimentation with limited supplies. If you do not have the means to completely close off the system, then your data may be skewed." – Teacher 5
- "I feel like I never have great luck with a calorimeter lab." – Teacher 1

Summary of KoSc

Teachers demonstrated their KoSc by providing explanations of the content, describing how they apply their scientific knowledge during instruction, and identifying difficulties that their students may face with thermodynamics. The most common themes for KoSc were:

- The abstract nature of thermodynamics can make it difficult to understand or teach these topics.
- Students have varying degrees of prior knowledge related to thermodynamics concepts.
- Many aspects of thermodynamics are too advanced for the typical high school chemistry class, so teachers' additional knowledge was extensive compared to what they plan to teach.

In conjunction with each other, these circumstances may lead to a higher occurrence of misconceptions, which teachers would need to be aware of and correct.

<u>Examples of KoG</u>

The next code for the CoRe assignment relates to KoG, which may include learning goals for scientific literacy, real-life application, and integrated understanding.[41] This code specifically aligned with the prompting question for the importance of learning the concept. Teachers stated that student understanding of their chosen topic is essential for providing foundational knowledge for concepts that will appear later in their unit or course.

- "It is important for students to know this before they dive into further thermodynamics with finding the enthalpy of reactions, enthalpy of formation, and bond energies." – Teacher 17
- "Students need to know how to properly calculate heat for a process and describe how the heat is flowing, because they will need to apply these skills to more complex concepts like determining enthalpy of reaction and solution." – Teacher 22

Similarly, many teachers stated that learning these concepts is integral for students moving forward to further chemistry or science education.

- "Students wishing to further their chemistry education beyond a high school chemistry course will be expected to use these concepts when studying more advanced enthalpy topics including Hess's Law, Enthalpies of formation and bond enthalpies." – Teacher 33
- "Students will need this especially if they plan on majoring in a hard science. It is important they have foundational knowledge of this concept." – Teacher 23

- “Students may find that a solid understanding in the first law of thermodynamics will solidify their understanding of more advanced thermodynamics concepts that they may encounter later in their education, especially if they plan on pursuing a STEM career.” – Teacher 5

Some teachers shared goals and motivations for teaching these topics in terms of real-world connections.

- “I have a mission to teach my students climate science at any possible turn…In this era I believe that climate science is of paramount importance for any citizen to understand.” – Teacher 3
- “Thermal chemistry and the transformation of energy is essential for life processes and is something we use to solve problems like heating homes, powering engines, heating food, icing injuries, de-icing roads and planes, etc… One of the priorities of the work I’m doing is creating culturally sustaining curriculum for learning science. When developing units and lessons, we look for connections to Lakota culture.” – Teacher 18

<u>Summary of KoG</u>

Teachers were able to demonstrate their KoG by sharing the importance of introducing thermodynamics topics to their students. The most common themes in teacher responses were:

- That teachers feel responsible to introduce topics that will prepare their students for topics later in their course or for future scientific study.
- That it is important for students to understand the real-world applications of thermodynamics, despite the abstract nature of these concepts.

The goals mentioned by participants surpassed simply teaching these concepts because it is in the standards. This reveals aspects of participants' teaching philosophies and educational motivations.

Examples of KoSt

The next code is KoSt, which may focus on different learning levels, needs, interests, prior knowledge, ability, learning difficulties, and misconceptions.[41] First, teachers identified the class to which they would teach their chosen topic. Many teachers chose to teach their concept in an advanced chemistry course, such as Honors, AP, or a dual credit college level course ($N = 12$). The remaining six teachers chose to include instruction of thermodynamics topics in a lower-level general chemistry course. The next component of the CoRe asked teachers to share their knowledge about students' thinking based on experiences and interactions they have had with students in the classroom. As stated in teachers' KoSc, many students lack the necessary prior knowledge for understanding thermodynamics topics. More examples were given in responses to this prompting question.

- "It will be my job to gauge their different science backgrounds and abilities and also mathematical backgrounds and abilities in order to plan appropriate instruction. I will steer my methods based on what I learn about my students." – Teacher 23
- "Students may not have had any prior chemistry instruction. Likewise, their graph analysis skills might need scaffolding." – Teacher 18

Other teachers discussed prior knowledge that their students already possess.

- "Students have pretty good foundations in state changes from early years in science education." – Teacher 2
- "Students have a very basic knowledge of thermodynamics. They have completed Algebra II so the math associated with specific heat is not usually an issue." – Teacher 1

Teachers also discussed knowledge of their students' attitudes that may play a role in their reception of this lesson and also inform how teachers approach instruction.

- "Though math difficulties may be a barrier, student attitudes towards difficult or complicated problems may also play a factor in how this concept is received or taught. Some students, if not taught clearly and straightforwardly, may quit before they begin. Other students, who may not struggle initially, may not persevere if they don't succeed right away. It is necessary to be clear, straightforward, and methodical in teaching in order for students to gain not only knowledge, but also confidence." – Teacher 30
- "Most of my students will complain about Lewis structures, and since many of them didn't do well on that, I imagine several of them will also struggle with bond enthalpies – especially when their answer is based on their Lewis structure. I will have to give some sample problems with the Lewis structure drawn already." – Teacher 25

Participants shared knowledge about their students' thinking by discussing what teaching methods their students seem to prefer.

- "Students love concrete examples and clear-cut procedures or algorithms for solving problems, especially in first-year Chemistry. I will need to make sure that

I introduce the topic with very familiar situations and gradually introduce the newer concepts for them." – Teacher 17

- "Students would do best to start the unit off with an engaging phenomenon." – Teacher 27

When discussion factors influencing their teaching, participants also demonstrated their KoSt.

- "Students tend to struggle with math and can perform calculations incorrectly, especially when there are negatives and multiple operations are involved." – Teacher 22
- "Students struggle with the concept that heat can be added or removed from a system, but there is no such thing as 'cold.' A system gets 'colder' when heat is removed." – Teacher 31
- "It could depend on student response on how long I would stay on the subject. If students understand the concepts quickly, I would move onto the next topic faster. If they are struggling with grasping the topic, I would revisit it and possibly revise how I would teach it to students." – Teacher 14

Many teachers highlighted the impact of students' prior knowledge on their teaching choices, which combined their KoSt, KoCO, and KoT. This intertwining of knowledge bases demonstrated improvements to the quality of their overall PCK.

- "Students in chemistry class have varying levels of mathematics skills. Most are concurrently taking Algebra II but several are enrolled in calculus or pre-calculus." – Teacher 33

- "At my school, physics is taught before chemistry. So in theory, the students would come in with an understanding of work and heat, but I can't count on that." – Teacher 19
- "I think I will be influenced by what I learn from my students regarding their past learnings about thermochemistry and how heat and energy move." – Teacher 23

Summary of KoSt

Teachers expressed their KoSt by stating how they know their students learn best, how students' prior knowledge informs their teaching approach, and what attitudes their students may possess during this lesson. The main themes for KoSt were:

- Students' level of prior knowledge informs how teachers approach instruction of thermodynamics, regardless of if students possess the necessary foundational knowledge.
- That teachers are aware of student behavior and attitudes related to concepts that are challenging to visualize.

Participants demonstrated that their current students impact how they approach teaching chemistry.

KoCO

The next code relates to KoCO, which may include knowledge of state and local standards.[41] In the CoRe assignment, teachers are asked to name the standards that are relevant to their chosen topic. Most teachers used NGSS standards (N = 13), while some used guidelines from the AP Chemistry framework (N = 4). The remaining teachers used state- or department-specific standards (N = 4). One teacher stated that their school does not use curricular standards, but they gave AP and NGSS standards related to their chosen concept.

Similar to the Semester 1 CoRe, all teachers were aware of what types of standards are used in their respective teaching contexts and provided the standards that were relevant to their current teaching situation. Teachers are aware of the standards that guide their instruction and can adjust their teaching of content to meet these standards.

Examples of KoT

The next code is KoT, which involves the discussion of teaching methods and activities.[41] First, teachers were asked to share the teaching procedures related to their chosen topic. Most teachers included multiple teaching strategies in their response to this prompting question. Many teachers ($N = 10$) decided to use small group work involving practice problems in their plan for this lesson. Simulations and models ($N = 7$) and direct instruction ($N = 8$) were also commonly chosen instructional methods. Several teachers decided to bring labs or demonstrations into their teaching of this topic ($N = 9$), while others included discussion ($N = 4$) or writing ($N = 2$) in their teaching of thermodynamics topics.

Participants also referred to past teaching experiences that informed their lesson design.

- "I think when I introduce the energy ideas heat and temperature are going to be hard for students to separate in their minds. I made the mistake this year of just lumping the two together and then it messed up some of our discussions later about particles and KMT." – Teacher 6
- "I also know that they are very bad with cold turkey labs. My students tend to do better when given examples or modeling is shown before a lab. That is why

before the lab we will as a class establish the definitions of each of the three vocabulary words that are surrounding the lesson for that day." – Teacher 7

Teachers discussed the importance of making real-world connections to their chosen chemistry concept.

- "Students making connections to real life. A lot of time students do not see the connections to their life to what they learn in science class, so I need to make sure to provide those connections to them, so they have better understanding of what happens in different types of systems." – Teacher 29
- "I think with the First Law of Thermodynamics and calorimetry, it's easier for students to understand because they see this in their everyday lives." – Teacher 25

Participants also identified connections between different scientific disciplines that they would try to highlight in their teaching of thermodynamics.

- "There are aspects of state functions that I think would make great crosscutting connections for students in my AP Chemistry course who have some background in Physics as well, with ideas of position and energy conversions and conservation. If there are students with that background, it would certainly have an impact on how I would offer this material in our course." – Teacher 2
- "The first law of thermodynamics is often thought of as the transfer of energy from one kind to the other, and the more complicated understanding of the combination of energies inside a system is slow to make an appearance…I feel that the latter understanding could bridge the gap between chemistry and physics and give students more real-world applications of this level of chemistry." – Teacher 5

One teacher discussed the impact of their own learning challenges on their instruction of these topics.

- "Honestly, the personal difficulty I have experienced in learning these concepts will certainly influence my teaching." – Teacher 17

Summary of KoT

Teachers' discussion of teaching procedures allowed for the bridging of knowledge bases, especially KoSt and KoG. The most common themes for KoT were:

- That all teachers utilized multiple teaching strategies in their lesson design for a thermodynamics concept.
- That many teachers were able to provide reasoning for why they chose specific teaching procedures for a specific concept and for a specific group of students, showing that teachers possess topic-specific PCK and knowledge of their students.

Through their discussion of teaching strategies, participants demonstrated their ability to weave various knowledge bases together, showing higher quality PCK.

Examples of KoA

The next code is KoA, which details teachers' knowledge of formal and informal assessments and feedback.[41] Many participants discussed assessment methods in the teaching procedures section of the CoRe.

- "Low Stakes Formative Assessments – practice, feedback for me, mistakes encouraged Medium stakes Formative Assessment (MCM) to add some heat (pun) and help them feel comfortable making mistakes, but also encouraged to take it more seriously." – Teacher 27

- "The next part would give the students a formative assessment (worksheet) to practice the topics. The questions will vary from matching the example given to endothermic/exothermic to solve for the energy in the reaction when bonds are broken or formed then explain why it is endothermic or exothermic… The last step would be a summative assessment over the material. This would be in the form of a quiz. This would test the students' knowledge on the topics as well as give insight for me to see if students have any knowledge gaps or misunderstanding." – Teacher 14
- "The groups will then share out about what these different motions are, and I will be able to check that there is understanding before proceeding." – Teacher 3
- "Exit Ticket: students identify what type of a system is each example as a check for understanding. Based on their replies, a teacher can see if the concept needs to be retaught." – Teacher 29

Teachers then discussed how they would assess student understanding or confusion. Like with the teaching procedures, most participants chose to utilize multiple assessment methods. The assessment methods identified in the Spring 2022 CoRe were checking for understanding through direct questioning ($N = 9$), practice problems ($N = 9$), listening to student discussions ($N = 8$), informal assessments during simulations or lab activities ($N = 8$), formative or summative tests/quizzes ($N = 7$), and presentations ($N = 3$). Two teachers chose to use "LOL diagrams" – which are energy bar charts – to check for understanding.

Many teachers discussed how assessments will help identify any misconceptions that can be corrected before moving forward.

- "I will also listen to their conversations throughout the lab for any misconceptions they have. We will address these misconceptions during the whole class discussion at the end of the lab." – Teacher 31
- "In warm up 3-4 students picked randomly to see what students know about systems, so I can see what misconceptions are needed to be addressed in this lesson." – Teacher 29
- "These concepts also permit rather simple and quick formative assessments to gauge progress toward mastery of the ideas, and adjustments based on the misconceptions that still exist, if any, in a class." – Teacher 2

Teachers also demonstrated their reasoning behind assessing students, thus revealing aspects of their teaching philosophies.

- "The quiz is something students can continue to rework and improve their score on, so it's a formative assessment, not a summative assessment. It's possible that with time some of the students that are missing part or all of the understanding of a concept can demonstrate that they've grown in their understanding, so it's important to me to let them continue to show this growth and retake the quiz." – Teacher 19
- "I can pose additional questions to groups and individuals that may require more help…Through careful analysis of student work, I can identify areas of strength or weakness. Additional practice can be assigned if needed." – Teacher 33

Summary of KoA

Teachers in the Spring 2022 semester described methods of assessment they would use to check for student understanding of thermodynamics concepts. The main themes for KoA were:

- That some teachers intentionally embed assessment in their teaching procedures, demonstrating both a knowledge of assessment methods and an understanding of the purpose of assessment.
- That teachers are aware of multiple ways to assess student understanding and confusion.
- That teachers understand how to adjust instruction based on assessment results.

Participants were able to describe methods of assessment they would use in their classrooms to gauge the quality of learning and teaching that took place.

KoR

The final code in Codebook 2 relates to KoR, which discusses materials and activities that teachers utilize in their classrooms.[41] Participants demonstrated their KoR by identifying which resources they would use in their teaching of thermodynamics topics. In the teaching procedures section of the CoRe, teachers expressed knowledge of lab activities and demonstrations ($N = 2$), PhET simulations ($N = 3$), videos ($N = 1$), readings ($N = 1$), and graphing software ($N = 1$) that could be used to engage students or aid in the learning process.[71]

Throughout the CoRe, teachers provided materials and activities that they planned to use for instruction of their chosen topic. Only 33.3% of the participants explicitly identified resources, while most described their teaching procedures without indicating any specific resources.

Summary of CoRe Data

In Semester 2, participants completed a CoRe on a challenging thermodynamics topic. Although many teachers found these topics to be more “abstract,” they were able to explain their current content knowledge of thermodynamics. Teachers used knowledge of their own students’ learning styles, attitudes, and prior knowledge to create a well-rounded lesson plan. By combining their KoSt and KoT, teachers demonstrated improved PCK quality. Participants were able to provide good rationale for their teaching choices and involved multiple teaching and assessment strategies in their CoRe. All participants possessed six of the seven PCK knowledge bases, while only a third of the participants explicitly included KoR. The main themes that appeared in the CoRe were:

- Teachers were able to differentiate instruction in their teaching of a challenging thermodynamics topic. By combining their KoSc and KoT, teachers demonstrated improved PCK quality.
- Participants were able to provide sound reasoning in support of their teaching choices. By demonstrating their KoCO, teachers revealed improvements to their PCK quality.
- Participants were able to design lessons with students’ prior knowledge in mind. By combining their KoSt and KoT, teachers demonstrated improvements to the quality of their overall PCK.

Although teachers content knowledge may vary from course to course in the MS program, the completed CoRe modules in Semester 2 were more focused and reflective than those in Semester 1. In addition, teachers provided much more explanation and reasoning related to their teaching philosophies than they had in the first iteration of the CoRe assignment. This demonstrated improvements to the quality of their overall PCK from Semester 1 to Semester 2.

Module Survey – CoRe

After completing the CoRe assignment, teachers were invited to complete a survey about their experience creating a CoRe for their topic. Eighteen teachers completed the CoRe module survey in Spring 2022. In the survey, participants were asked if they would feel comfortable teaching their chosen topic without preparation. Of the 18 teachers, 14 (77.8%) would not feel comfortable, 3 (16.7%) would feel comfortable, and 1 (5.6%) would feel comfortable teaching without preparing beforehand but did not think it was a good teaching practice to do so. When asked about their confidence level on a scale of 1 to 6 for teaching their concept, the average confidence score was 4.526. Upon creating a CoRe for their topic, 8 teachers (44.4%) did not find it challenging and 10 (55.6%) did find it challenging, with 4 of these teachers finding only some aspects to be challenging. The CoRe module survey was coded using all Codebooks 1 and 4.

<u>*Codebook 1*</u>

Coding frequencies for Codebook 1 can be found in Table 166 below.

Table 166. Module Survey Coding Frequencies for Semester 2 CoRe – CB1

Code	**Abbreviation**	**Total Number of Teachers Represented (N = 18)**	**Percentage of Total Responses (%)**
Attitudes	A-c	5	27.8
Knowledge	K-p	4	22.2
	K-c	17	94.4
Skill	S-c	3	16.7
Teaching	T	17	94.4
Feedback	F	7	38.9
Modules	M	18	100
Reflection	R	16	88.9

Attitudes (A-c)

Five teachers discussed current attitudes resulting from completing the CoRe as a part of the CHEM 772 course. One teacher reflected on their attitudes toward the content and how they felt about their ability to teach thermodynamics topics.

- "I am interested in the concepts from this portion of the course and believe I have room for growth in my pedagogy related to these concepts." – Teacher 2

Three teachers shared attitudes related to confidence in their content knowledge. One teacher shared lower confidence since they had yet to teach it, while the other teacher described feeling more confident to teach their topic in the future.

- "I have a plan/idea of how I want to teach it. I am still not super confident since it is new and I have not done this lesson before." – Teacher 7
- "I do feel more confident in the topic if I ever teach the subject." – Teacher 14
- "This module has made me more confident in my own understanding so that I can be more confident in teaching to students." – Teacher 30

The CoRe also helped one teacher become more comfortable with thermodynamics content.

- "This exercise helped me get more familiar and comfortable with the topic which will benefit my students in the future." – Teacher 23

The CoRe revealed participants' confidence and comfort level in teaching thermodynamics topics and established in which areas teachers may need to focus their growth in the future. Three teachers shared more positive comments, while one described hesitance about their confidence in teaching new material.

Examples of Knowledge (K-p and K-c)

In terms of prior knowledge, four teachers discussed their knowledge of thermodynamics content prior to taking the CHEM 772 course. All four teachers described a low level of prior knowledge.

- "I realized that I had a huge misconception about types of systems before I took this course." – Teacher 29
- "My thermochemistry background is very weak, mostly because the thermochemistry unit I teach is bare bones - I teach Hess' Law, energy signs and specific heat equations." – Teacher 25

- “I have always struggled with this concept and I have to refresh my memory every time I teach it.” – Teacher 31
- “My level of knowledge about the topic wasn't enough before.” – Teacher 23

After taking the CHEM 772 course, however, almost every teacher described their current level of knowledge. Several teachers described content knowledge gains.

- “I stole some ideas from things people shared in the discussion board for the activities I chose, and it helped solidify my knowledge and understanding of the concepts.” – Teacher 31
- “This course has provided me with additional background knowledge and a deeper understanding of several of the concepts that would be taught in a high school chemistry classroom.” – Teacher 33
- “I have a deeper understanding of the intermolecular interactions that drive energy transformations.” – Teacher 18

Many teachers discussed how improvements to their thermodynamics content knowledge has directly impacted their teaching.

- “I've learned quite a bit in this course that will help me better serve my students.” – Teacher 23
- “Now since I have a correct understanding of it, I can actually teach types of systems for the first time.” – Teacher 29
- “This course has opened up many options that I can add to my curriculum, and while some is a bit beyond what my students can or should handle, I've also realized there are some topics that I can add in to make the unit more robust, such as bond enthalpy.” – Teacher 25

- "This course has allowed me to better see how all of these concepts (energy, heat capacity, enthalpy) are all related, and have given me a better understanding of how to get these to connect and flow together when establishing a scope and sequence of a course." – Teacher 5

Teachers also mentioned that their teaching confidence would increase if they had more content knowledge. Multiple participants described how they hoped to gain more knowledge. Some examples are listed below.

- "Reading about it from multiple sources and learning about concepts that take it from theoretical to practical or experiential." – Teacher 3
- "Having someone else teach it to me first or have me work through the concept ahead of time." – Teacher 16
- "I think continued work with some of the underlying concepts - those beyond the scope of what I'm required to teach personally - would reinforce my content knowledge." – Teacher 2
- "More knowledge in the concept." – Teacher 1

<u>Summary of Knowledge (K-p and K-c)</u>

When thinking back on their experience completing the module most of the teachers (N = 17) discussed their current knowledge after participating in the CHEM 772 course. Four teachers shared weaknesses in their thermodynamics knowledge prior to the course, and all four teachers experienced knowledge gains in the Spring 2022 semester. The most common themes related to current knowledge were:

- The CHEM 772 course allowed teachers to improve their chemistry content knowledge and correct prior misconceptions. Their development of KoSc demonstrated improvements to their PCK.
- Improved content knowledge directly impacts participants' ability to teach thermodynamics topics more effectively, which demonstrates their development of PCK through improved KoSc.
- Teachers have a desire to gain more knowledge in this content area to gain confidence in their teaching of these topics.

Many participants related their chemistry content knowledge to their teaching ability and pedagogical knowledge, showing a connection between these knowledge bases.

Skill (S-c)

Three teachers shared their current skill level after completing the CoRe module. Both teachers discussed changes in their pedagogical skill, including how this would manifest in their interactions with students.

- "Before doing this module, my teaching of this concept would have been very direct and focused simply on the calculations and memorizing the signs of q and w in different situations. Now, I see myself pushing the students to come to the understanding of the basics of the First Law of Thermodynamics BEFORE introducing the equations and calculations. Now, I would first focus on the conceptual part of the content and then move into the more advanced mathematical considerations of the content." – Teacher 17
- "Having struggled through the content for myself, I am more able to see where students may struggle as well." – Teacher 30

- “I think I am better able to make some cross-cutting connections to other topics from earlier in my curriculum year now that I've worked through the content thus far, which will make some of my work with students on earlier concepts that are more abstract somewhat easier to access now that I have another perspective to offer them as an ‘on ramp’ to grasping those abstractions.” – Teacher 2

Through their experience in the CHEM 772 course and with the CoRe module, participants practiced more teaching skills that they can apply in their own classrooms.

Examples of Teaching (T)

In the CoRe module survey, all teachers but one ($N = 17$) discussed their teaching. Many participants stated that more teaching experience would help increase their teaching confidence of their chosen concept. Some examples are given below.

- “I think having more teaching experience would be the first that would make me more comfortable.” – Teacher 5
- “I would feel more confident once I teach this concept at least once, so I can see what is working and what does not.” – Teacher 29
- “Practice with a class. I imagine after I run through this for the first time during 4th quarter, I will modify some things and also add to it.” – Teacher 27
- “Experience would make me feel more confident teaching this concept. I will feel more confident teaching it the 2nd or 3rd time than I will the first.” – Teacher 31

Teachers also described how the CoRe module has influenced their teaching of their chosen topic. Some participants stated that they were unsure, since they have not been able to teach their CoRe lesson yet.

- “We have not yet gotten to thermodynamics in my chemistry class, so I cannot say yet.” – Teacher 19
- “Unfortunately, I have already taught this topic this school year, but I will use it next school year.” – Teacher 1
- “I have gotten some extra activities or ways of teaching the concept that I plan to try next year with students.” – Teacher 22

Other teachers explained why they may not use their CoRe lesson in the future due to time constraints.

- “I am not sure if I can justify teaching this with limited time, but I think there are some good ideas to start from and launch into other important chemistry ideas.” – Teacher 3
- “The only concepts from thermochemistry that I had to teach was heat calculation/ calorimetry. This content really doesn't even cover that. I feel like if I am honest this would not be a lesson I do unless I had the time.” – Teacher 7

One teacher stated that their teaching has not been transformed because they do not teach these topics.

- “It honestly hasn't because I do not teach thermochemistry.” – Teacher 14

On the other hand, some teachers mentioned bringing this topic into their curriculum because of the CoRe.

- “I have never taught this, but now that we've gone more in detail with it, I want to add it to my curriculum.” – Teacher 25

- “I have never taught this concept in chemistry before, but I think I have a pretty good start on some lessons and activities to help my students understand the concepts.” – Teacher 31
- “We were not teaching thermochemistry beyond the terms endothermic and exothermic except in AP Chemistry. Now I have some ideas and a plan for implementation across all levels of chemistry taught at our school.” – Teacher 27

Summary of Teaching (T)

Most participants expressed how the CoRe allowed them to reflect on their own teaching and how more teaching experience could positively impact their confidence. The most common themes related to teaching were:

- The creation of a CoRe allowed teachers to access new resources and methods for teaching a challenging thermodynamics concept, even if they may not have the time to teach this lesson in their classrooms.
- For some, the CoRe inspired teachers to bring thermodynamics into their chemistry courses.
- More experience teaching thermodynamics topics would increase participants’ teaching confidence.

Feedback

Data coded as feedback was sent directly to MS program instructors.

Examples of Modules (M)

All participants (*N* = 18) reflected on their experience completing the CoRe module in the CHEM 772 course. All teachers talked about the challenges associated with creating a CoRe for their chosen concept. Many teachers identified challenges related to anticipating students' reactions to the lesson.

- "The parts that were challenging were when I would have to anticipate student outcomes or how they would react to the material." – Teacher 19
- "I had to think more deeply about why I wanted the students to know the concepts, what was going to be difficult for them, and how to intentionally present the material to maximize understanding." – Teacher 17
- "It made me think in detail of what students will struggle with before beginning the lesson" – Teacher 1

Some teachers discussed the challenge of creating a lesson for a challenging topic.

- "The only real challenging portion was coming up with the 'lesson' which was the prompt relating to how will you teach this lesson. Given that this is a challenging topic, knowing an effective way to teach it is tough, but I guess that is the point." – Teacher 3
- "Considering that it was a difficult concept for me to teach, it was difficult to create the CoRe. But, having to find resources and/or pedagogy to teach this concept has definitely helped me make more sense of it." – Teacher 16

Teachers also described the utility of completing the assignment's discussion forums to help decide the topic for which they would create a CoRe.

- "The discussion posts were helpful for thinking through ideas." – Teacher 18
- "The weekly discussion boards leading up to this assignment helped a lot." – Teacher 31

For one teacher, the CoRe gave them the opportunity to apply new content knowledge.

- “Writing this CoRe was actually fun because I was working with ‘new’ material that I haven't taught.” – Teacher 25

Summary of Modules (M)

Participants shared their experience completing the CoRe assignment and which aspects were challenging for them. The main themes for statements coded as modules were:

- The CoRe allowed teachers to reflect on how their students would react to thermodynamics instruction and think about how they could adjust their teaching to better aid students in the future.
- Although the CoRe was challenging for some to create, it was a worthwhile experience and led participants to create more effective lessons.
- Multiple teachers stated that the CoRe discussion forums were useful for choosing a topic, showing the importance of discussion and interaction with peers in the MS courses, particularly related to teaching.

Examples of Reflection (R)

The CoRe module survey allowed teachers to reflect on their experience creating a CoRe and what this meant for them in terms of growth in their teaching and learning. Teachers first considered how their completion of the module allowed them to think about how they teach thermodynamics topics.

- “Completing this module has provided me with the opportunity to really consider all aspects of how I present basic thermodynamics concepts.” – Teacher 33
- “I looked more carefully at the performance expectations with NGSS and that helped me think about student tasks and assessing student learning.” – Teacher 18

Teachers also reflected on more difficulty they faced in creating a hypothetical lesson for a challenging topic, relating both to their chemistry and pedagogical knowledge.

- “It was also challenging personally because I chose a challenging topic, so I had to make sure that I had a good understanding of the material before working on CoRe, and that took me some time and effort to get to a place where I felt comfortable enough to teach the material…Without the content, I would not have chosen or understood the material that I chose to teach for the CoRe assignment.” – Teacher 19
- “I find that it is always quite challenging to plan how to teach a single concept without explaining your whole scope and sequence leading up to covering the topic and without the resources present.” – Teacher 5

The CoRe allowed participants to reflect on their own growth as teachers.

- “This assignment asked me to grow a little, but in a direction that I needed to go.” – Teacher 27
- “As a Chemistry teacher, I am always trying to reflect on how to better myself as a teacher. This exercise helps me to reflect on what is difficult for me so I can better serve my students in the future...This type of guided reflection makes me better as a teacher.” – Teacher 23

Teachers also reflected that it was time consuming to complete the CoRe due to the level of reflection necessary for planning a new, effective lesson on new content.

- “It was not challenging but time consuming. For me I am a work backwards kind of person. So this project helps me accelerate this process. In order to answer the questions properly I cannot give a vague answer. I need to really understand the lesson I want to teach and how I want to teach it." – Teacher 7

- "It was very time consuming to connect what I know about a specific piece of content with my experience on how students learn. I feel it is valuable to think about where students may struggle and what things can interfere with their successful understanding of this topic." – Teacher 33

Summary of Reflection (R)

In the module survey, many teachers reflected on their experience completing a CoRe for a challenging thermodynamics concept. The main themes for reflection were:

- The CoRe allowed teachers to experience growth in their topic-specific PCK by giving teachers the opportunity to think about how they would teach new thermodynamics content in their current classes.
- The CoRe gave participants the opportunity to reflect on all aspects of their lesson design while applying new content knowledge.

The CoRe module assignment allowed for meaningful reflection and a discussion of teacher growth through their experience in the MS program.

Codebook 4

Codebook 4 then allowed me to break down the teacher statements by source of motivation. Each comment was assessed to determine the focus of the comment, either focused on the participant's learning, their students' learning, or the participant's teaching. Coding frequencies are displayed in Table 167.

Table 167. Module Survey Coding Frequencies for Semester 2 CoRe – CB4

Code	**Abbreviation**	**Total Number of Teachers Represented (*N* = 18)**	**Percentage of Total Responses (%)**
Learning-focused	L-f	16	88.9
Student-focused	S-f	13	72.2
Teaching-focused	T-f	18	100

Most teachers (72.2%) demonstrated all three motivations in their CoRe survey statements. All teachers (*N* = 18) shared teaching-focused comments. A selection of responses is given below.

- "This type of guided reflection makes me better as a teacher." – Teacher 23
- "From now on, when I teach systems, I will make sure to address the matter exchange as well. Before, when I taught systems, I only talked about energy exchange." – Teacher 29
- "I prefer to have documents made, homework assignments printed, and lab experiences planned out before teaching. So I guess my answer depends on what you mean by 'teaching.' Lecturing? Yes. Having a discussion? Yes. Leading activities? Yes. But to me, teaching means so much more than just doing those things." – Teacher 30

Most of the teachers ($N = 16$) also included topics related to their own learning, which were coded as learning-focused. Some examples of teacher comments are given below.

- "I have a deeper understanding of the intermolecular interactions that drive energy transformations." – Teacher 18
- "I think this module has solidified my understanding of the equation related to the first law of thermodynamics and has given me extra practice in evaluating the signs of q and w, which is the reason I chose this topic for this assignment." – Teacher 5
- "This course has provided me with additional background knowledge and a deeper understanding of several of the concepts that would be taught in a high school chemistry classroom." – Teacher 33

Many teachers ($N = 13$) gave comments in the CoRe module survey that focused on their own students. A selection of responses is given below.

- "The only hard part was deciding on a concept. There were many, but eventually I went with one that I felt students would use later on in college." – Teacher 25
- "I had to think more deeply about why I wanted the students to know the concepts, what was going to be difficult for them, and how to intentionally present the material to maximize understanding." – Teacher 17
- The CoRe module "made me think in detail of what students will struggle with before beginning the lesson. It also made me reflect on items they have struggled with in the past and what I need to do to prepare myself for the current students." – Teacher 1

Summary of Module Survey – CoRe

The CoRe module survey gave participants the opportunity to share their thoughts on their experience completing a CoRe in the CHEM 772 course. All participants shared teaching-focused statements, revealing that the CoRe allowed them to think about how they could improve their own teaching effectiveness. For this set of data, there was a greater emphasis on the teachers' learning than on their students' learning, revealing that participants placed a greater focus on their own learning of thermodynamics content, possibly due to the challenging nature of the material. The most common themes from the Spring 2022 CoRe module survey were:

- The CoRe allowed teachers to reflect on their growth as educators, including increased teaching confidence, increased content knowledge with respect to thermodynamics (KoSc), and improved pedagogical knowledge (KoT). By improving their KoSc and KoT, teachers improved their overall PCK.
- Teachers were able to apply new knowledge of a challenging concept to a teaching context based on what they had learned in CHEM 772. By combining their KoSc and KoT, participants demonstrated improvements to their PCK quality.
- The CoRe prepared teachers to bring thermodynamics concepts into their own instruction. Again, teachers demonstrated improved PCK quality through the intertwining of multiple knowledge bases.

This was the second iteration of the CoRe assignment and one teacher mentioned that because participants "completed a CoRe last semester in 771 and had that basis of familiarity with how the format works," it was not as challenging overall. Although teachers found CHEM 772 content to be more abstract and challenging in general, they were still able to apply new content knowledge and think about how they would teach these topics to their students. Thus, they combined their KoSc and KoT, which indicated improved PCK quality. Many teachers stated that they experienced growth while creating the CoRe module, indicating that teachers grew professionally through their experience in the MS program in Spring 2022.

Midway Course Reflection (CHEM 778)

The midway course reflection asked participants to think about what they had gained pedagogically through CHEM 778: Chemistry Teaching Strategies. This survey was coded using Codebooks 1, 2, and 4. Data coded as feedback was sent directly to MS program instructors.

Codebook 1

Coding frequencies for Codebook 1 can be found in Table 168.

Table 168. Midway Course Reflection Coding Frequencies– CB1

Code	**Abbreviation**	**Total Number of Teachers Represented (*N* = 15)**	**Percentage of Total Responses (%)**
Attitudes	A-p	1	6.7
	A-c	3	20
Knowledge	K-p	1	6.7
	K-c	5	33.3
Skill	S-p	2	13.3

	S-c	8	53.3
Teaching	T	15	100
Feedback	F	9	60
Experience	E	1	6.7
Interaction	I	6	40
Reflection	R	11	73.3

Attitudes (A-p and A-c)

Some teacher statements related to their attitudes, including feelings and emotions that they have experienced regarding teaching and learning. One teacher shared a past feeling that evolved after taking CHEM 778.

- "I felt that at year 6 that I had exhausted every way of how to teach chemistry. Boy was I wrong." – Teacher 7

Three other teachers described changes to their disposition after participating in the chemistry teaching strategies course. Teachers discuss the impact of having new chemistry and pedagogical knowledge from the work they have done in the course.

- "I feel much more confident, and competent, in my understanding of chemistry and teaching the content…I think the confidence I have from content knowledge has really helped me to branch out and allow my students to become the scientists." – Teacher 16
- "The Sharing Project with my partner was a really refreshing and motivating… The chance to hear how others use some of the same activities that I use (or very

similar ones) but with little tweaks and alterations that make things so much more fresh or effective is an ongoing JOY for me." – Teacher 2

- "Because of the Creativity readings, discussions, and project, I am finding myself more open to teaching differently." – Teacher 17

Teacher statements indicate that participants in CHEM 778 were exposed to new teaching strategies that positively impacted their teaching motivation and confidence.

<u>Knowledge (K-p and K-c)</u>

Teachers then shared comments related to their knowledge before and after their participation in the CHEM 778 course. One teacher shared how new knowledge has influenced them to change their practice.

- "I do feel that I have more ideas in how to center the phenomenon and engineering goals throughout the unit now which is something that I tended to feel like I tended to discuss but then rarely reference back to until the end of the chapter." – Teacher 4

Four other teachers discussed how the course has impacted them by giving them new teaching strategies that they can use in their classrooms.

- "The topics from this course have given me a better understanding of the topics in modeling and student discussions in class." – Teacher 6
- "The biggest way this course has impacted my class was giving me new ideas to teach…This has given me a great insight not only other ways to teach, but how to focus my teaching." – Teacher 7
- "Now I have more strategies and practices I can use as a teacher." – Teacher 29

- “I have learned new teaching strategies, new lab ideas, new demos, and new ways to engage my students. I have also learned that creativity can be shown through a variety of formats, which makes it easier to incorporate creative components in my lessons.” – Teacher 31

The CHEM 778 course has transformed teachers by giving them new pedagogical knowledge and allowing for reflection on their current teaching practices. Participants in the course were able to gain new ideas and knowledge that could be applied to their future instruction.

Examples of Skill (S-p and S-c)

In terms of skill, two teachers have shared examples of their past pedagogical skill and how new knowledge and experiences have given them a new or refreshed skillset for teaching.

- “I have a vivid memory from AP chemistry students asking my why a strong acid is strong and I had no idea how to answer. I now know and can actually explain it so that it makes sense.” – Teacher 16
- “I am trying to avoid telling students if an answer is correct immediately, so everyone has time to process their thoughts and share their ideas. This is a work in progress. There have been a few demonstrations where I asked students what they thought would happen before I did the demo. In the past, I probably just did the demo and explained what was happening.” – Teacher 31

Several participants discussed new skills that they gained through the CHEM 778 course, with many discussing how they facilitate student learning. In addition, multiple teachers discussed how they had shifted assessment methods to check for student understanding.

- "I try to do new and different things in class to get kids to think and interact with each other, all while discovering the content through investigation... I have made a concerted effort to reintroduce argumentation through claim, evidence and reasoning." – Teacher 16
- "I'm trying to incorporate opportunities for my students to think creatively and grow beyond just providing the right answer… I'm definitely looking forward to incorporating more 'what if' questions to the labs and activities to get students to think about the situation and use what they know to build their answer." – Teacher 25
- "I think I have tried to pay more attention to how I talk and present information. I want to ensure I am getting my point across, while also giving students the opportunity to learn and grow as well." – Teacher 20
- "I now try to incorporate some opportunities for students to think creatively and explain their reasoning... I have also pushed my students more to put evidence behind their explanations and not do it for them." – Teacher 14
- "I am giving less direction and providing more opportunities for students to 'figure things out.'" – Teacher 17
- "I have been more cognizant in referencing back to the phenomenon more often in classes where I already had started the process." – Teacher 4
- "There is more student talk in my classes. I am finding 'holes' in understanding prior to a summative assessment." – Teacher 9

Summary of Skill (S-p and S-c)

Through the chemistry teaching strategies course, many participants honed their pedagogical skill. The main themes for the skill code were:

- Teachers applied skills that they gained in the CHEM 778 course to their teaching, showing that they have brought their program learning into the classroom.
- Many comments regarding teachers' current skills demonstrate a shift toward student-focused teaching, including new ways teachers have checked for student understanding and allowing for more student independence in the classroom.

Teacher statements related to skill reflected a direct impact of the MS program on teaching effectiveness.

Examples of Teaching (T)

All teachers shared statements related to their current teaching. Because this course focused on chemistry teaching strategies, many of the comments described new strategies or ideas the participants had learned about over the course of the semester. Some examples of teacher comments are given below.

- "I have been much more intentional about creating opportunities for students to be creative in my classroom." – Teacher 20
- "The concepts and ideas from the Ambitious Science Teaching book have really given me lots of new strategies to try and has really reinforced some of my thoughts on teaching chemistry." – Teacher 16
- The course content "has also helped in discussing other techniques that people use and adapting those to fit my teaching style." – Teacher 14

- "I am transitioning to the teaching style and activities found in AST…. I will continue to have a creative project each semester." – Teacher 9

Many teachers shared the ideas from CHEM 778 that they have utilized in their classrooms. A selection of responses is given below.

- "The daily work is hard to inspire creativity due to the students learning the material, but once students practice the material with a hands-on lab or activity, I can pose challenging questions that make them think outside the box. For example, we did a calorimetry lab recently and after the students determined the metal and calculated the percent error, they were given different situations (adding hot water with the hot metal, adding cooled metal, adding hot water to cool water, using a beaker or paper cup instead of styrofoam) and had to justify their answer of what would happen." – Teacher 25
- "I am definitely using some of the ideas from the Creativity book and discussion in my classroom…I am offering more assignments that are open-ended and allow students to pursue their own interests." – Teacher 17
- "I have used talk as a tool for learning, modeling, and learning how students are creative." – Teacher 1
- "I have actually added activities to my curriculum. Examples are as follows: Group work including pictorial representations of lab; Individual work to include representing student lab work in mini posters and pictorial representations of chemical phenomena." – Teacher 3
- "I did implement some exit card strategies and grouping strategies already." – Teacher 23

Although some participants have not yet had the opportunity to bring new ideas into their instruction, they shared ideas they would like to use in the future.

- "I don't know that it has impacted my teaching in large ways yet, just baby steps because of time constraints but it is something that I plan to work on incorporating things more for next year." – Teacher 4
- "I have not changed anything for this upcoming year, but I will be changing things for next year. I plan to try to implement the AST process in my upper level physics class and find new ways to increase creativity." – Teacher 6
- "This year, I have only really incorporated the sharing project and creativity projects in my classes. However, I have a lot of ideas of changes I want to make for next year." – Teacher 31

Summary of Teaching (T)

Because the Midway Course Reflection survey focused on how the CHEM 778 course impacted participants' teaching, many of the survey responses related to teaching. The main themes for teaching were:

- Teachers have taken ideas from the course texts to use in their classrooms, thus having a direct influence on participants' teaching practice.
- The CHEM 778 course gave participants many chemistry teaching strategies, which teachers either brought into their classroom or planned to bring into their instruction in the future.
- Teachers were willing to make changes to their teaching considering what they had learned in the MS program.

Participant comments reveal that teachers have an openness to new ideas and have demonstrated an inclination to apply new ideas to their teaching.

Feedback

Data coded as feedback was sent directly to MS program instructors.

Experience

One teacher detailed their experience participating in the CHEM 778 discussion forums.

- “The discussion forums have been very helpful this semester. They generally discussed how to teach creatively and also how to reflect on ourselves as practitioners so we can best meet the needs of our students.”

This teacher directly detailed their experience participating in the CHEM 778 course and described the purpose of the discussion forums from their perspective.

Interaction

Several teachers highlighted the importance of interactions that took place in the CHEM 778 course, particularly by learning new ideas from their peers in discussion forums or in group Zoom meetings.

- “I've also learned a lot of tips and tricks from more experienced teachers.” – Teacher 20
- “I was able to learn a lot of new ideas from my peers.” – Teacher 23
- “I enjoy the discussion boards and the new ideas all the teachers bring that I can use in my classroom.” – Teacher 1

Teachers also discussed the importance of adapting these ideas to their own teaching and reflecting on their own teaching practice.

- "I keep coming back to this, but my main takeaways that have actively impacted my teaching are examples and tricks from my colleagues in this program…The conversations that we have had during Zoom have placed constant thoughts in my head that are making me think about what my teaching is in general." – Teacher 3
- "It has also helped in discussing other techniques that people use and adapting those to fit my teaching styles." – Teacher 14

One teacher reflected on how their interactions in the MS program inspired them to have pedagogical discussions with colleagues in their school.

- "The interactions with the rest of the cohort and Instructor A have been great inspiration to reflect and dig further into how I do things…. I hope the environment and the positive experience of what we've done this semester in the discussion boards and the Tuesday evenings will grow into an ongoing practice for me, and that I'll catalyze those kinds of conversations with my colleagues. I know that there are others in my dept who would really enjoy this environment and the benefits of it." – Teacher 2

Participants in CHEM 778 were able to take away ideas and inspiration from their interactions with each other and the instructor that directly impacted their teaching effectiveness.

<u>Reflection</u>

Many teachers (73.3%) used this survey to reflect on how the CHEM 778 course impacted them and their teaching. A selection of reflective comments is given below.

- "I think I've realized there is a lot of value in creative opportunities." – Teacher 20

- “I have a lot to learn, but I have a good starting point that I can continue to build on as I continue to teach.” – Teacher 16
- “I REALLY love reflection and discussion and the open-ended opportunities for conversations that are FAR TOO RARE in my everyday existence.” – Teacher 2
- “These topics have pushed me to take a hard look at myself and some of my practices and ask how I can do better.” – Teacher 23
- “It has made me think about how I am challenging my students.” – Teacher 14
- “One of my biggest takeaways so far is that I should always try new things and evolve as a teacher. I will never be perfect, but by trying new things and expanding my knowledge, I can definitely improve year after year.” – Teacher 20

Codebook 2

Codebook 2 was used to analyze teachers’ demonstration of PCK in the Midway Course Reflection. Coding frequencies can be found in Table 169.

Table 169. Midway Course Reflection Coding Frequencies – CB2

Code	**Abbreviation**	**Total Number of Teachers Represented (*N* = 15)**	**Percentage of Total Responses (%)**
Knowledge of science	KoSc	1	6.7
Knowledge of goals	KoG	5	33.3

Knowledge of students	KoSt	2	13.3
Knowledge of curriculum organization	KoCO	1	6.7
Knowledge of teaching	KoT	14	93.3
Knowledge of assessment	KoA	7	46.7
Knowledge of resources	KoR	13	86.7

KoSc

Because the Midway Course Reflection was given to participants enrolled in the CHEM 778 course, which focused on science pedagogy, teachers were not requested to share their chemistry content knowledge. One teacher described their KoSc by detailing a lab they had recently done in their classroom.

- "For example, we did a calorimetry lab recently and after the students determined the metal and calculated the percent error, they were given different situations (adding hot water with the hot metal, adding cooled metal, adding hot water to cool water, using a beaker or paper cup instead of styrofoam) and had to justify their answer of what would happen." – Teacher 25

KoG

A third of the teachers shared comments related to their goals for teaching chemistry, including allowing students to experience scientific investigation and approach scientific problems with creativity. Many responses related to creativity due to the text for the course *Developing Creativity in the Classroom.*[73] Some examples of teacher statements related to goals are given below.

- "I feel like I've been challenged to make my classroom and courses more inviting for creativity and learning experiences beyond what I've been doing. A lot of my assignments are very black and white, and now I'm trying to incorporate opportunities for my students to think creatively and grow beyond just providing the right answer." – Teacher 25
- "Because of the Creativity readings, discussions, and project, I am finding myself more open to teaching differently, with more choices for my students, more opportunities for them to become engaged in projects, and more activities that encourage them to be creative." – Teacher 17
- "I have also tried to incorporate more creativity and independent student investigation into class this year."– Teacher 16

These comments demonstrated teachers' desire to utilize teaching strategies and curricula that fit their goals for student learning.

<u>KoSt</u>

One teacher demonstrated their KoSt by reflecting on diverse learners.

- The course topics "have reminded me that students learn different ways." – Teacher 1

In the CHEM 778 course, a sharing project allowed pairs of teachers to collaborate remotely, allowing for class interaction across multiple schools or states. The creativity project focused on encouraging creativity in the classroom. One teacher discussed their students' reactions to participating in these projects.

- "The students really enjoyed the creativity project and I think working with a class from a different state for the sharing project was a nice change of pace for them." – Teacher 31

<u>KoCO</u>

The only comment related to KoCO focused on how one teacher planned to restructure their unit based on what they had learned in CHEM 778.

- "I do feel that I have more ideas in how to center the phenomenon and engineering goals throughout the unit now which is something that I tended to feel like I tended to discuss but then rarely reference back to until the end of the chapter." – Teacher 4

<u>KoT</u>

Almost every teacher ($N = 14$) described their KoT by describing teaching strategies and ideas they had learned about in CHEM 778. A selection of teacher statements is given below.

- "This [course] has given me a great insight not only other ways to teach, but how to focus my teaching." – Teacher 7
- "It has made me think about how I am challenging my students. I now try to incorporate some opportunities for students to think creatively and explain their reasoning. It has also helped in discussing other techniques that people use and adapting those to fit my teaching style." – Teacher 14
- "I have learned new teaching strategies, new lab ideas, new demos, and new ways to engage my students. I have also learned that creativity can be shown through a

variety of formats, which makes it easier to incorporate creative components in my lessons." – Teacher 31

- "I think I have tried to pay more attention to how I talk and present information. I want to ensure I am getting my point across, while also giving students the opportunity to learn and grow as well. One of my biggest takeaways so far is that I should always try new things and evolve as a teacher. I will never be perfect, but by trying new things and expanding my knowledge, I can definitely improve year after year." – Teacher 20
- "Argumentation is something I forgot about this year because of COVID. So I have made a concerted effort to reintroduce argumentation through claim, evidence and reasoning." – Teacher 16

In this survey, participants reflected on the new knowledge and ideas they had gained from the CHEM 778 course and how this will impact their future instruction. Teachers expressed a desire to improve their teaching and become more effective educators by employing new teaching strategies.

Examples of KoA

The next code is KoA, which details teachers' knowledge of formal and informal assessments and feedback.[41] Almost half of the participants ($N = 7$) demonstrated their KoA by describing how they would evaluate student learning using ideas they learned in CHEM 778. Some teachers discussed using student discussion to check for understanding.

- “I have been more cognizant in referencing back to the phenomenon more often in classes where I already had started the process, I am also more aware of some of the ways to help students discuss and share out their thinking.” – Teacher 4
- “I am transitioning to the teaching style and activities found in [*Ambitious Science Teaching*].[72] There is more student talk in my classes. I am finding ‘holes’ in understanding prior to a summative assessment.” – Teacher 9
- “I am trying to avoid telling students if an answer is correct immediately, so everyone has time to process their thoughts and share their ideas.” – Teacher 31

Other teachers decided to give students more freedom with assignments, which would allow teachers to assess students’ skill level and comfort with the material without as much guidance.

- “I have also pushed my students more to put evidence behind their explanations and not do it for them. I have added more activities where students do not get a full set of instructions and have to come up with their own.” – Teacher 14
- “I am giving less direction and providing more opportunities for students to ‘figure things out.’ I am offering more assignments that are open-ended and allow students to pursue their own interests.” – Teacher 17
- “I'm definitely looking forward to incorporating more ‘what if’ questions to the labs and activities to get students to think about the situation and use what they know to build their answer.” – Teacher 25

Summary of KoA

The Midway Course Reflection allowed participants to think about how they have adjusted their assessment methods in accordance with new teaching strategies. The statements focused on different approaches toward assessment, but all teachers indicated a shift toward student-driven learning.

KoR

Many teachers (N = 13, 86.7%) demonstrated their KoR by sharing ideas and resources that they gained through CHEM 778. A selection of responses is given below.

- "The concepts and ideas from the Ambitious Science Teaching book have really given me lots of new strategies to try and has really reinforced some of my thoughts on teaching chemistry.[72]" – Teacher 16
- "The Ambitious Science Teacher is THE book I needed to move me forward in my pedagogy…There are many small things that I am keeping a Google list of: videos, particular demonstrations, additional websites and books.[72]" – Teacher 9
- "I have also saved several links and resources from the discussion board posts and thought about how I can incorporate some of the things we discussed to make my lessons more engaging and student centered." – Teacher 31

Participants gained resources from the CHEM 778 course and are aware of strategies and materials they would like to use in the future.

Codebook 4

Codebook 4 was then used to analyze the motivations participants had when making statements in the Midway Course Reflection. These coding frequencies can be found in Table 170.

Table 170. Midway Course Reflection Coding Frequencies– CB4

Code	**Abbreviation**	**Total Number of Teachers Represented (*N* = 15)**	**Percentage of Total Responses (%)**
Learning-focused	L-f	9	60
Student-focused	S-f	10	66.7
Teaching-focused	T-f	15	100

All teachers shared teaching-focused comments, and more than half described learning-focused (*N* = 9) and student-focused (*N* = 10) motivations. Because the course was related to pedagogy, it was expected that all teachers shared comments focused on their own teaching. Some examples are given below.

- “Now I have more strategies and practices I can use as a teacher.” – Teacher 29
- "I felt that at year 6 that I had exhausted every way of how to teach chemistry. Boy was I wrong. This has given me a great inside not only other ways to teach, but how to focus my teaching.” – Teacher 7
- “I keep coming back to this, but my main takeaways that have actively impacted my teaching are examples and tricks from my colleagues in this program. There have been a few classroom activities I already adopted this spring in my class.” – Teacher 3

The second most common motivation for participants in the CHEM 778 course was focus on their own students' learning. A selection of responses is given below.

- "It has made me think about how I am challenging my students. I now try to incorporate some opportunities for students to think creatively and explain their reasoning." – Teacher 14
- "I am giving less direction and providing more opportunities for students to 'figure things out.' I am offering more assignments that are open-ended and allow students to pursue their own interests." – Teacher 17
- "I have also tried to incorporate more creativity and independent student investigation into class this year. I think the confidence I have from content knowledge has really helped me to branch out and allow my students to become the scientists. Very little direct instruction from me at the start of a unit and a lot more discovery on the part of the students." – Teacher 16

Over half of the teachers also included statements that were focused on their own learning (*N* = 9, 60%). Some examples of participant comments are given below.

- "I have learned new teaching strategies, new lab ideas, new demos, and new ways to engage my students. I have also learned that creativity can be shown through a variety of formats, which makes it easier to incorporate creative components in my lessons." – Teacher 31
- "The topics from this course have given me a better understanding of the topics in modeling and student discussions in class." – Teacher 6
- "Favorite ideas have been about how to better incorporate phenomenon, modeling and engineering." – Teacher 4

Summary of Midway Course Reflection

Teachers demonstrated improvements to their PCK through their reflection on how CHEM 778 has impacted their teaching. Participants mainly demonstrated their KoR and KoT as components of their PCK by describing teaching strategies and implementation ideas they learned through the course. All participants shared statements with teaching-focused motivations. Nine teachers discussed the learning that took place in the course; however, much of the learning related to pedagogy, so most statements were coded as teaching-focused statements. Several teachers also discussed their KoA by expanding on how these new teaching strategies impact how they assess student understanding. By combining their KoA and KoT, teachers demonstrated improved PCK quality. Many comments related to how teachers would adjust their instruction to support better student learning, with two-thirds of participants revealing student-focused motivations. These comments demonstrated teachers' combination of their KoT and KoSt knowledge bases, which indicated improved PCK quality. Participants shared their KoG as a component of PCK by talking about an emphasis on bringing creativity into the classroom, a direct impact of the course's discussion of *Developing Creativity in the Classroom*.[73] Participants also referenced the course's other text, *Ambitious Science Teaching*, thus demonstrating the impact of course discussions on participants' desire to apply these ideas to their own instruction.[72] This indicates that the MS program has had an impact on participants' pedagogical knowledge and the examples outlined above support teachers' development of PCK. The main themes for the Midway Course Reflection were:

- Participants in the CHEM 778 course demonstrated a willingness to utilize new chemistry teaching strategies in their instruction, which demonstrated flexibility in their teaching philosophies. Teachers were open to learning about new perspectives and ideas and applied what they learned to their own teaching. This development of their KoT indicated improvements to participants' overall PCK.
- Teachers made actual changes to their teaching through the Sharing and Creativity projects, which allowed teachers to apply new chemistry teaching strategies to their instruction, emphasizing teachers' willingness to make instant changes to their teaching. This also displayed improvements to teachers' overall PCK through their participation in the CHEM 778 course.
- Participants' exposure to new teaching strategies influenced their teaching effectiveness by allowing them to reflect on how they introduce chemistry topics, foster student learning, and assess student understanding. By combining their KoSc, KoSt, KoT, and KoA, teachers demonstrated improved PCK quality.
- CHEM 778 directly impacted teachers' pedagogical knowledge and skill, highlighting an important component of the MS program. CHEM 778 enabled participants to enhance their KoT as a component of their PCK. This course ignited teachers' motivation to apply more effective teaching methods to their own practice, thus demonstrating a transformation of participants' pedagogy.

Teaching Script

In Spring 2022, the Teaching Script was also administered in CHEM 772: Thermodynamics, as this was the only core content course offered. The Teaching Script assignment was due during the second half of the course after the CoRe. The Teaching

Script was analyzed using Codebook 2 to assess participants' PCK. Table 171 displays the codes from Codebook 2 that appeared in the Semester 2 Teaching Script.

Table 171. Teaching Script Coding Frequencies for Semester 2 – CB2

Code	**Abbreviation**	**Total Number of Teachers Represented (*N* = 18)**	**Percentage of Total Responses (%)**
Knowledge of science	KoSc	18	100
Knowledge of goals	KoG	17	94.4
Knowledge of students	KoSt	18	100
Knowledge of curriculum organization	KoCO	18	100
Knowledge of teaching	KoT	17	94.4
Knowledge of assessment	KoA	15	83.3
Knowledge of resources	KoR	18	100

Just like the CoRe assignment, the Teaching Script assignment was created to gain information about participants' PCK. Like the CoRe, many of the Codebook 2 codes were present in participant responses, as all teachers should possess prior PCK.

Examples of KoSc

The first component of PCK represented in the Teaching Script is KoSc, which includes science content, scientific practice, the nature of science, and scientific progress.[41] Participants identified a challenging topic that they would like to teach related to the topics from the second half of the CHEM 772 course. The most chosen topics were entropy and microstates (N = 10) and Gibbs Free Energy and spontaneity (N = 5). Two teachers chose to teach topics related to thermochemistry, while one focused on reversible reactions. Many teachers decided on their topic due to students' struggles with the abstract nature of thermodynamics concepts.

- "I believe that entropy would be the toughest concept to teach because it is rather abstract, so getting students to visualize what is happening at an atomic level would be challenging." – Teacher 5
- "Students tend to be weaker on abstract based concepts such as placement of particles, energy, and entropy." – Teacher 7

Topic choice also depended on students' level of prior knowledge.

- "Students have a difficult time understanding the basic concepts such as exothermic and endothermic. They come in with a limit amount of knowledge in thermochemistry." – Teacher 1
- "I think the reason that this continues to be a struggle is that students don't usually get to my AP chemistry class (where this content first shows up in their experience in science classes) with any kind of background in the ideas of entropy or free energy." – Teacher 2

Many teachers explained the importance of effectively teaching a challenging topic due to misconceptions or misunderstandings that arise.

- "Entropy would be challenging to teach because there are often missing pieces of background knowledge and also misunderstandings that trip students up. So this is a topic that is very important for me to teach as a high school teacher." – Teacher 23
- "I found that microstates should function to increase understanding of entropy, but without proper treatment, scaffolding and connection could function to decrease understanding and unnecessarily 'muddy the waters.'" – Teacher 3

One participant found their topic to be challenging to teach because they had no prior experience.

- "I have never taught this concept before." – Teacher 29

Only 77.8% of the teachers (N = 14) provided examples of their prior thermodynamics knowledge, but most (N = 17) gave examples of additional knowledge they could share with the more curious student. A selection of responses related to teachers' content knowledge is given below.

- "Entropy is a state function which predicts the direction of spontaneity. Spontaneous processes are those that proceed in the forward direction without outside help after the process is initiated. In any process, probability will always favor the state for which energy is more dispersed." – Teacher 30
- "Conservation of energy means that the total change in energy is always equal to the total energy transferred in or out of the system." – Teacher 18

- "If $\Delta G=0$, the reaction is in equilibrium and nothing will happen macroscopically." – Teacher 25

Finally, teachers shared what they viewed to be the fundamental components of their chosen concept. A selection of responses is given below.

- "Entropy is the measure of the number of ways that energy can be shared among particles. Entropy increases if the number of ways of distributing the available energy among the particles is increased." – Teacher 7
- "Fundamentally, I'd want to communicate to the students that entropy is S, a state function, that measures the amount of disorder within a system. I'd talk about how reactions that increase the overall entropy of the universe are favored, and I'd talk about how in some reactions you see the entropy of the system increased, while in others you see the entropy of the surroundings increased." – Teacher 19

Some teachers provided less detail of the fundamental components by stating which aspects of the concept were important for students to understand. Some examples are given below.

- "I believe the fundamental components are knowing the definitions and relating that to chemical reactions." – Teacher 14
- "Understanding the flow of heat is a fundamental component of the concept." – Teacher 1

Summary of KoSc

Through the Teaching Script, most participants were able to express a deep understanding of their chosen concept. The module allowed participants to reflect on what they knew about their topic versus what content knowledge they would share with their students. The most common themes for KoSc were:

- Teachers were able to identify a challenging thermodynamics concept and explain why it is important to teach effectively to their students.
- Most teachers were able to distill their content knowledge into a statement of the fundamental components of their chosen topic.
- When demonstrating their content knowledge of their chosen concept, some teachers went more in depth than others. This potentially identifies a difference in the quality of participants' content knowledge.

Most teachers chose entropy as their chosen topic, which was also the topic used for the Teaching Script example. I did not notice any similarities between the provided example and participants' responses, other than general real-world examples, so this did not seem to have an impact.

Examples of KoG

The next code for the Teaching Script assignment relates to KoG, which may include learning goals for scientific literacy, real-life application, and integrated understanding.[41] Most teachers (N = 15, 83.3%) revealed their KoG by sharing why they thought it was important for their students to learn their chosen concept. Most teachers found it important for their students to understand the topic because it related to other thermodynamics concepts.

- "It is important for students to understand entropy in practical situations because it will help them determine the spontaneity of a reaction, the reversibility of a reaction, the likelihood of a reaction." – Teacher 17

- “Students need to understand how the concepts of enthalpy and entropy go together to determine if a reaction is spontaneous or not.” – Teacher 22
- “A true understanding of thermodynamics is at the heart of a true understanding of chemistry at the level that is required of an AP student. It's impossible to consider equilibrium, electrochemistry, and other core concepts of the class without being able to interconnect those ideas with the glue of thermodynamics.” – Teacher 2

Participants also found it important to teach these topics to students so they have foundational knowledge that would be useful in future science courses.

- “In addition, some students will have to take higher level chemistry classes for their future careers and Gibbs free energy will be covered in those classes.” – Teacher 31
- “For college-bound students, especially those pursuing a degree in science, may find that a solid understanding of thermodynamic processes will give them a better standing of other molecular processes they will learn about through their college education.” – Teacher 5

Teachers also related thermodynamics topics to real-world examples, stating that knowledge of these concepts helps students better understand the world around them.

- “The concept of entropy is one of the major driving forces for processes. Not only chemical processes, but also biological and natural processes can be explained by a favorable entropy value.” – Teacher 30
- “I think the concept of entropy in general is very important for students to understand. It helps them understand the universe in general.” – Teacher 19

The next section of the Teaching Script directly asked teachers to share some real-world connections specifically related to their chosen concept. Only ten teachers (55.6%) were able to identify real-world examples, showing that almost half of the participants omitted answering this question. This may imply that teachers were not able to make real-world connections. A few examples are listed below for those who responded to this question.

- "An endothermic reaction would be an ice pack. There are ice packs that once you break the material within them, the substance cools off. This happens because energy is going into the system and bonds are being made." – Teacher 14
- "Gibbs free energy measures the maximum work done by a system, where the free energy is stored in the bonds of the substances. When discussing energy, we can relate it to biochemical processes, such as metabolism, ATP, and different cycles found in living organisms." – Teacher 25
- "So for my classes, the real world connection comes from considering the entropy of water in the solid, liquid and gas phases and drawing conclusions about entropy." – Teacher 16

<u>Summary of KoG</u>

Teachers were able to describe the importance of teaching thermodynamics to their high school chemistry students. The most common themes were:

- That teaching a challenging thermodynamics topic will prepare students for topics later in the course or in future education/careers.
- That thermodynamics topics are interconnected, so having a deep understanding of one component aids in a better understanding of thermodynamics as a whole.

- That although some teachers have placed importance on including real-world applications in their instruction, only 55.6% of the participants were able to identify real-world examples of their chosen topic.

Although thermodynamics topics tend to be more abstract, teachers were still able to identify the importance of teaching these topics effectively, particularly with respect to their students' learning. Almost half of the teachers did not identify real-world connections, potentially revealing a gap in teachers' understanding of the relevance of thermodynamics.

Examples of KoSt

The next code is KoSt, which may focus on different learning levels, needs, interests, prior knowledge, ability, learning difficulties, and misconceptions.[41] All teachers chose to teach their challenging topic to a general chemistry course ($N = 10$) or to an advanced class, such as AP or Honors ($N = 8$), except for one teacher who is currently out of the classroom "developing culturally sustaining science kits for K-12 usage that integrate Lakota cultural knowledge and Western Science." Two teachers included above listed both advanced and general chemistry courses as the student learning context.

Participants ($N = 16$) also demonstrated knowledge of their students by explaining misconceptions that teachers expect to occur when teaching their chosen topic. A selection of responses is given below.

- "Another misconception is that entropy can have a negative value. Entropy can decrease in value, but it will never be a negative number." – Teacher 17

- "I think a misconception would be that spontaneity is determined solely by entropy." – Teacher 19
- "A misconception would be keeping endothermic with breaking of bonds and exothermic with creating of bonds." – Teacher 14

Teachers then shared reactions or questions they would expect from their students during this lesson. Based on prior experiences with students, teachers share how their students will react to the mathematical aspect of thermodynamics.

- "I expect students to do quite well with the calculations associated with entropy. They almost always get the math pretty quickly because it is very straightforward. Where students struggle is the explanation part (on short answer questions for example). They can do the math (usually) but when it comes to explaining what the math means, they struggle." – Teacher 16
- "In my past experience, students always have more struggles with concepts that involve math." – Teacher 23
- Students "will gravitate towards the math explanation, and will struggle more with the conceptual part (i.e. signs and conditions)." – Teacher 25

Some of the questions participants came up with related to the concepts themselves.

- "How do we know if a process will be spontaneous? How can we calculate the values?" – Teacher 30
- "How does water freeze spontaneously into a more ordered state than liquid water?" – Teacher 17
- "What is the difference between entropy what we are learning now and enthalpy what we were learning before?" – Teacher 7

Others came up with questions related to how scientific theories and principles were investigated and established.

- "How can scientists be sure that it is true? How did they prove that it is a law?" – Teacher 29
- "How do they determine the entropy, enthalpy, and Gibbs free energy values in the table?" – Teacher 31

One teacher demonstrated their KoSt by discussing how they would help students struggling with calculations.

- "it will be important to do many different examples with the students that are guided, and then do some thoughtful pairing so that students who have grasped the math can be paired with students who might need a little bit more help and structure in their calculations." – Teacher 19

Summary of KoSt

In the Teaching Script, participants shared how they would approach teaching their chosen topic with knowledge of their own students in mind. The most common themes for KoSt were:

- That most teachers ($N = 16$, 88.9%) understood the misconceptions associated with their chosen topic and had plans for how they could address or correct these misconceptions.
- That teachers knew which aspects of chemistry their students would struggle with based on past experiences, as well as which components would allow students to thrive.

- That teachers were able to hypothesize a range of potential questions their students may ask during a thermodynamics lesson.

Many of the misconceptions, challenges, and questions related to the mathematical components of thermodynamics, as well as the conceptualization of these topics. Teachers were able to pull from prior experiences with students to anticipate student reactions to their instruction.

Examples of KoCO

The next code relates to KoCO, which may include knowledge of state and local standards.[41] Participants (N = 14, 77.8%) explained connections between their chosen concept and what concepts they currently teach in their classrooms. Many teachers already teach the concept in their course (N = 12). Others mentioned that the topic does not tie into their current teaching but relates to courses they may teach in the future (N = 2).

After discussing how their concept ties into what they teach, teachers were asked to identify relevant standards. Teachers included a range of standards, including those from the NGSS (N = 12), AP guidelines (N = 5), and state-specific standards (N = 2). Two teachers also included standards used in their schools/departments, including one teacher who stated that "the school where [they] work is project-based, which means [they] don't use the NGSS standards to guide [their] curriculum." Some teachers included multiple groups of standards; for example, some teachers included relevant NGSS standards and their local state standards.

To conclude the curriculum organization section, teachers were asked to make decisions about what they planned to teach about their chosen topic. The prompting question asked participants to consider what students need to know about their thermodynamics topic. All teachers but one were able to describe what they intend for students to learn. Many teachers responded by stating intended student learning outcomes for the Teaching Script lesson. A selection of responses is given below.

- "Students must have an understanding of enthalpy that includes being able to do math problems with enthalpy and find changes in enthalpy with the correct values." – Teacher 23
- "Students must know what information can be ascertained from the sign of both enthalpy and entropy. They need to be able to predict the signs for enthalpy and entropy for a given reaction or process." – Teacher 22
- "My students need to know how to calculate Gibbs free energy from the standard enthalpy and standard entropy values at a specific temperature. They also need to be able to use Gibbs free energy to determine if a reaction is spontaneous or nonspontaneous." – Teacher 31

Summary of KoCO

Teachers demonstrated their KoCO by being able to make decisions about what to teach based on the relevant student learning context. Participants were able to identify standards related to their chosen concept and were able to present intended student learning outcomes for their Teaching Script lesson. The main themes for KoCO were:

- Teachers were able to apply their knowledge of a challenging concept to their teaching. Participants had the ability to determine what aspects of the content to teach in accordance with standards, students' prior knowledge, and goals for student learning.

- Teachers focused their Teaching Script by stating what aspects of their chosen concept fit into their course's curriculum and were manageable regarding what students needed to learn at this moment in time. Making decisions about what to teach demonstrated their KoCO and demonstrated their PCK.

Examples of KoT

The next code is KoT, which involves the discussion of teaching methods and activities.[41] Teachers were asked to share the teaching procedures related to their chosen lesson as well as their timeline for covering this concept. For this topic, many teachers decided to use labs/demonstrations ($N = 11$) and discussion ($N = 8$). Several teachers also embedded practice problems in small groups into their lesson plan ($N = 11$), especially during instruction of a challenging thermodynamics concept. The final two categories of teaching strategies mentioned in Teaching Scripts were direct instruction ($N = 6$) and simulations/modeling ($N = 4$).

Teachers also shared their reasoning for including a variety of teaching strategies, particularly with respect to student understanding.

- "I am using a variety of pedagogical tools to teach this concept. This concept is very abstract and I plan to use two different activities to help students gain a clear understanding of entropy." – Teacher 33
- "I will utilize scaffolding by discussing entropy on a more macroscopic scale before discussing entropy at a molecular level. I will also use visuals in order to portray different microstates in an attempt to make the concept of entropy more visual." – Teacher 5

- "Warm Up at the beginning of the class to activate their prior knowledge; Hands on activity [to] help students explore and better understand the concept while working in groups, then revise their models [to] analyze their initial thinking and apply new knowledge." – Teacher 29

When describing their timeline for the lesson, instruction ranged from one class period to eight class periods. The timeline depended on the topic chosen, as some topics were broader than others. Many mentioned time constraints that impacted the length of their timeline, even for the teacher who included the longest timeline.

- "The timeline for this would be 6-8 class periods. I wish I could devote more time to it but there is just so much to cover." – Teacher 23
- "The timeline for this lesson will span over three days. I hate making long lessons, but the fun ones are long. This I feel is the best way to make it feel organic and not rushed for a 45-minute period." – Teacher 7

In the Teaching Script assignment, many teachers (*N* = 15) described how they would address misconceptions during instruction. Many teachers would have further discussion to involve students in the process of correcting misconceptions (*N* = 11).

- "I think it would be a good lead into a group discussion or debate so that students can figure it out and generate ideas on their own." – Teacher 23
- "When misconceptions arise, I will react accordingly. I might have them discuss a concept or question I ask with their neighbor before we discuss it as a class." – Teacher 31

Others would use labs or demonstrations to help students better visualize the topic (*N* = 5).

- “I think that if I have a demo set up ready for if these misconceptions come true that have a perpetual motion device like one of the drinking birds or spinning rings with balls and then have students mimic the motion with a textbook. This will get them the idea that a reversible process is able to return to its initial state, work is constantly being done, and it is efficient.” – Teacher 6
- “I will attach a battery to show that the nonspontaneous reaction can be ‘forced’ to occur if there is an external energy supply. I will explain the difference between the reaction in the demo (outside power source for nonspontaneous reaction) and the reactions in the lab activity (activation energy).” – Teacher 22

<u>Summary of KoT</u>

In their description of teaching strategies and how they would address misconceptions, teachers demonstrated their KoT. The main themes from this component of PCK were:

- Teachers designed their lessons with student learning in mind. All participants employed multiple teaching strategies and many teachers supported their instructional choices with reasoning related to student learning outcomes.
- Many teachers planned to involve students in the process of correcting misconceptions, highlighting their ability and desire to employ student-focused teaching strategies.

This Teaching Script allowed teachers to explain their teaching choices and revealed participants’ focus on student involvement in their own learning.

Examples of KoA

The next code is KoA, which details teachers' knowledge of formal and informal assessments and feedback.[41] Unlike the CoRe, participants were not asked to specifically share their assessment methods for their Teaching Script lesson. However, some shared formal and informal assessments they planned to use while discussing teaching procedures, which demonstrated their KoA (*N* = 5).[41] A few examples are given below.

- "I want to know that students paid attention and got something from the lesson, so at the end I am going to task them with an exit ticket." – Teacher 6
- "Facilitating: Walking around the room is a great way to formally assess students as well as just making sure all students are participating equally…For students who are at lulls or naturally are thinking I pick their brain to see what they are thinking about and try to help them along." – Teacher 7
- "Students will work through a series of tutorial, visualization, and simulation questions that provide immediate feedback as well as help if they need it." – Teacher 25

Many other teachers (*N* = 10) included methods in their teaching procedures that could be classified as assessment methods, such as classroom discussion, but did not explicitly describe these as methods of assessment.

Summary of KoA

As with the Semester 1 Teaching Script, it is unclear whether these teachers were aware of how these methods can be utilized for assessment. Their responses to the Teaching Script module may not be the best indicators of teachers' PCK regarding assessment. The main theme of KoA was:

- The teachers who indicated specific assessment methods described the purpose of assessment, demonstrating that aspect of their PCK.
- Many of the teachers did not share assessment methods or include assessment methods without illustrating the role of assessment in their instruction.

In accordance with Semester 1 data, the Teaching Script did not explicitly encourage teachers to demonstrate their KoA.

KoR

The final code in Codebook 2 discusses KoR.[41] In the Teaching Script assignment, teachers were asked to identify materials that they would provide to students who wanted additional instruction. Participants provided links to videos ($N = 9$), readings ($N = 10$), PhET simulations ($N = 2$), and additional practice problems ($N = 4$). All teachers provided links or references to multiple materials or activities that could provide further instruction to more curious students. Some of the participants that shared links to readings identified sources used for CHEM 772, as well as using the OWL program that was used in the course, thus showing the impact of the MS program course on teachers' KoR.

Summary of Teaching Script Data

Through the Teaching Script module, most teachers were able to demonstrate each PCK knowledge bases, which indicated participants' possession of improved PCK through the CHEM 772 course. Participants demonstrated their desire to tailor their instruction of thermodynamics topics to their specific group of students by employing teaching strategies that would help their students learn best. By combining their KoSt and KoT, teachers demonstrated improved PCK quality. Teachers' goals, teaching choices, and instructional strategies focused on student learning outcomes. The Teaching Script allowed teachers to reflect on a challenging topic from CHEM 772 and the most common themes from this module were:

- Teachers created a lesson on their chosen topic that tied into other thermodynamics concepts. By combining their KoSc, KoCO, and KoT, teachers demonstrated improvements to the quality of their overall PCK.
- Teachers were able to focus their own chemistry content knowledge to the level of their students in their described teaching context, which combined their KoSc and KoCO and indicated improved PCK quality
- Participants used a variety of teaching strategies to make thermodynamics concepts more accessible for students and to identify misconceptions to promote better student learning. They demonstrated improved PCK quality by combining their KoSt and KoT.
- Most teachers did not explicitly express their KoA, which either reveals a weakness in teachers' PCK, a weakness in the module itself, or both. However, teachers likely identified and addressed misconceptions using their KoA.

This module demonstrated that most teachers possessed all aspects of PCK. Participants took knowledge gained from CHEM 772 and applied it to a teaching context, demonstrating their application of PCK and improved PCK quality through the combination of their KoSc and KoT.

Module Survey – Teaching Script

After completing the module, teachers were invited to complete a survey about their experience creating a Teaching Script for their topic. Nineteen teachers completed the Teaching Script module survey in Spring 2022. In the survey, participants were asked if they would feel comfortable teaching their chosen topic without preparation. Of the 14 teachers, 11 (78.6%) would not feel comfortable, 2 (14.3%) would feel comfortable, and only one would feel comfortable teaching without preparing beforehand but did not think it was a good teaching practice to do so. When asked about their confidence level on a scale of 1 to 6 for teaching their concept, the average confidence score was 4.60. Upon completing the module for their topic, all teachers found it challenging to create a Teaching Script, with two of these teachers finding only some aspects to be challenging. The Teaching Script module survey was coded using Codebooks 1 and 4.

Codebook 1

Coding frequencies for Codebook 1 can be found in Table 172.

Table 172. Module Survey Coding Frequencies for Semester 2 Teaching Script – CB1

Code	**Abbreviation**	**Total Number of Teachers Represented (N = 14)**	**Percentage of Total Responses (%)**
Attitudes	A-c	3	21.4
Knowledge	K-p	1	7.1
	K-c	10	71.4
Skill	S-c	1	7.1
Teaching	T	14	100
Feedback	F	4	28.6

Modules	M	12	85.7
Reflection	R	11	78.6

Attitudes (A-c)

A few teachers discussed their attitudes in relation to learning and teaching the course content through their experience creating a Teaching Script. One teacher discussed becoming more comfortable teaching a topic after having more experience.

- "I always feel more comfortable teaching a concept after I have taught it once or twice because I can think about what changes I want to make and make those changes before I teach it again." – Teacher 31

Two teachers discussed interest in teaching thermodynamics topics in the future.

- "I had not been exposed to the concept and ended up becoming fond of it and seeing the value pedagogically…I am excited to teach it someday" – Teacher 3
- "Looking forward to teaching it when I get back into the classroom next year."-Teacher 30

Examples of Knowledge (K-p and K-c)

Many teachers (71.4%) discussed their current level of knowledge after participating in the CHEM 772 course. One teacher discussed their knowledge of entropy before and after creating a Teaching Script. The module allowed them to reflect on how they think about the topic and introduce it to their students.

- "Previously, I simply considered entropy as 'more' - more disorder, more moles of gas, more movement. Now, after creating this module, I am thinking more carefully about 'why' entropy increases (more microstates) and how to account for that mathematically. I never considered it from that perspective before." – Teacher 17

Many teachers shared their current knowledge in the module survey. One teacher shared that there are still gaps in their understanding.

- "I still struggle to fully understand the concept." – Teacher 16

Several teachers discussed how the course content and module helped them learn, or relearn, thermodynamics concepts. Some examples are given below.

- "The content helped me a lot with understanding the concepts better." – Teacher 18
- "I have learned this content before, but it has been so long that I forgot most of what I learned. This course has helped me relearn these concepts." – Teacher 31
- "This course has led me to review this information and challenge if there are any misconceptions in my knowledge of this content." – Teacher 5
- The Teaching Script module "added significant depth and conceptual interconnections to my content knowledge and added some important missing pieces that make a lot of the ideas that I was treating as islands into one connected mass." – Teacher 2

Summary of Knowledge (K-p and K-c)

Through the CHEM 772 course, many participants experienced increases in their chemistry content knowledge. One teacher described needing further improvements to their knowledge of thermodynamics topics. Teachers also shared how the learning that takes place in the MS program informs their pedagogical skill. This learning helps teachers improve both their chemistry content knowledge (KoSc) and their knowledge of how to teach chemistry (KoT), demonstrating improvements to their overall PCK.

Skill (S-c)

One teacher discussed their current pedagogical skill after participating in the CHEM 772 course.

- “I think there have been a number of ways that gaining a deeper and more complete foundation for my own understanding will make a big difference in my own ability to answer questions in a cohesive and meaningful way for students who bring challenging questions to class during this content!” – Teacher 2

Deeper content knowledge allowed this teacher to become a more effective educator, with implications for improved student understanding. Gaining KoSc enabled this teacher to improve their KoT, a combination which indicates improved PCK.

Examples of Teaching (T)

When asked what would improve their confidence teaching their chosen topic, many participants identified gaining more teaching experience or practice teaching the topic. Some examples are given below.

- “Teaching it, then revising...then teaching it again...” – Teacher 3
- “I think more practice with teaching it and understanding what students will struggle with and what their misconceptions will be.” – Teacher 17
- “Experience. I feel that with teaching anything, the best way to get confident and comfortable doing it is to just do it, shake out the cobwebs, and reflect on what you can do better next time.” – Teacher 5
- “I would gain confidence by actually teaching it a few years!” – Teacher 30

The CHEM 772 course and Teaching Script assignment inspired teachers to bring thermodynamics topics into their instruction.

- “It has made me consider teaching more thermo in my regular class.” – Teacher 19
- “I have never taught thermochemistry concepts before, so this teaching script helped me figure out what my lessons over Gibbs free energy would look like if I ever get to teach that in the future.” – Teacher 31
- “Exposure to microstates, following a brief rebellion period of stating I would never touch these, made me want to teach it.” – Teacher 3

Other teachers shared how the course and module allowed them to think about how they could apply refreshed content knowledge to their teaching. Teachers discussed designing lessons for thermodynamics topics using new knowledge or materials.

- The module “has allowed me to begin to look for those analogies that help students understand the concept.” – Teacher 16
- The course “also gave me a little bit of background to help anchor my unit and come up with connections to students.” – Teacher 6
- “I have never taught Gibbs free energy, so coming up with the notes as well as what to cover and what not to cover was difficult. I had to imagine how I would break down the thermodynamics chapter and how I would teach the concept.” – Teacher 25

Summary of Teaching (T)

The Teaching Script module survey allowed teachers reflect on how they were applying new thermodynamics knowledge (KoSc) to a teaching context, indicating PCK. The main themes for teaching were:

- Participants would gain more confidence in their teaching through more practice and experience.
- The CHEM 772 course brought up new thermodynamics topics for the teachers and inspired them to bring more thermodynamics concepts into their instruction. Teachers combined their KoSc, KoCO, and KoT, demonstrating improvements to their PCK.
- The Teaching Script assignment allowed participants to make connections between their new content knowledge and their teaching by giving teachers the opportunity to thoroughly reflect on a thermodynamics lesson. Thus, teachers practiced their PCK through the combination of their KoSc and KoT.

In this module survey, teachers expressed a desire to have more experience teaching thermodynamics, in part because these topics were new for the teachers as learners. CHEM 772 provided foundational thermodynamics knowledge for participants to use in their teaching through the creation of a Teaching Script. This exercise provided an opportunity for teachers to practice and develop stronger PCK.

Feedback

Data coded as feedback was sent directly to MS program instructors.

Examples of Modules (M)

When referencing the modules, many teachers discussed the process associated with creating a Teaching Script, which included answering prompting questions about their lesson, creating an organization method such as slides, and drafting a verbatim script of their instruction. Some examples are given below.

- "I think the challenging part was thinking through the script of what the teacher should say. I don't usually write out a script for myself." – Teacher 19
- "Creating the script was fairly challenging process. I began by creating the activity and then created the script to go along with it… The teaching script did force me to create the activity with intentional and continued references to microstates and their relationship to entropy. I usually don't spend so much time scripting out what I will say and predicting student responses prior to teaching a particular concept." – Teacher 33
- "I will say that the process of planning the lesson was much easier than making the Teaching Script slides. Once I got the slides made, the teaching script itself was very easy since I was pretty much basing my lines off of the slides." – Teacher 25
- "The challenge was creating the content with which to use the script." – Teacher 3

One teacher decided to choose a topic that would be applicable in their classroom, ensuring that the Teaching Script assignment could be used in their teaching.

- "I kept mine very simple because I do not complete a lot of thermochemistry in my classroom so I tried to make it something realistic I would use in my classroom." – Teacher 1

- "It was challenging to find a sort of happy middle ground where the content would be challenging to teach and make a good choice for the Teaching Script and yet also be accessible and worthwhile for the level of my own class makeup." – Teacher 2

Another teacher discussed including components in their Teaching Script that were useful for the participant as a learner themselves.

- "I am a very visual person, so I included several visual representations in my teaching script that had helped me personally as a student in this course." – Teacher 17

One teacher compared their completed Teaching Script to the CoRe they created earlier in the CHEM 772 course.

- "I feel like I did an okay job, but it definitely was not as good as my CoRe assignment. That content connected to my classes better." – Teacher 6

Summary of Modules (M)

Through the module survey, many participants discussed their experience creating a Teaching Script. The main themes for the modules code were:

- The Teaching Script gave teachers an opportunity to view their lessons from a new perspective and to approach lesson design in a new way, especially in terms of scripting their instruction.
- Participants noted that the module allowed them to create a lesson for a topic they had never taught before.

The comments related to the module itself focused on the participants' development of a new thermodynamics lesson. The Teaching Script module allowed teachers to combine their PCK bases, particularly their KoSc and KoT. Through this exercise, teachers spent more time than usual preparing for instruction, which was especially beneficial for those who were teaching their chosen topic for the first time.

Examples of Reflection (R)

The final code for the Teaching Script module survey was reflection. Many participants took this opportunity to reflect on the CHEM 772 course, their experience creating a Teaching Script, and their teaching overall. Multiple teachers discussed the difficulty of choosing a topic for the module assignment.

- "The hardest part was deciding on what to focus on for the lesson." – Teacher 18
- "Thermo is not something I teach or will be teaching extensively so it was hard for me to pick topics in chapter 13 I cared about and wanted to make a lesson plan over." – Teacher 6
- "The content of this course was essentially summarized into the Gibbs free energy equation, so to me, it made sense to choose it for my teaching script. I think each variable is important in its own way, but it shows students that there is a reason to focus on each before focusing on the big picture." – Teacher 25

Other teachers reflected on challenges associated with the content itself.

- "I think the discussion of probability and microstates at the beginning of the chapter derailed me and made it hard to think about the concept from a more simple position." – Teacher 30
- "I still think its a tricky subject. It is especially tricky due to the many ways in which entropy is defined and redefined elsewhere. The term 'disorder' is used in some definitions and cautioned against in others." – Teacher 30

One teacher reflected on the nature of PCK.

- "Pedagogical content knowledge comes with time, experience, and practice, so I would need to teach entropy in this way quite a few times to feel more confident." – Teacher 17

Summary of Reflection (R)

The module survey allowed participants to reflect on their experience creating a Teaching Script on a thermodynamics topic. The most common themes were:

- It was challenging to create a lesson due to the challenging nature of thermodynamics concepts.
- It was challenging for teachers to apply this content to their teaching because this level of content is not relevant to the levels at which participants are teaching. For many teachers, the content in CHEM 772 was above what they would ever teach in their own courses. However, they were able to create a Teaching Script relevant to their current curriculum, demonstrating improved PCK through the intertwining of their KoSc, KoCO, and KoT.
- Reflection was necessary for teachers to think about how to bring challenging thermodynamics content into their instruction. This module allowed teachers to apply their PCK to the teaching of CHEM 772 topics.

Codebook 4

Codebook 4 then allowed me to break down the teacher statements by source of motivation. Each comment was assessed to determine the focus of the comment, either focused on the participant's learning, their students' learning, or the participant's teaching. Coding frequencies are displayed in Table 173.

Table 173. Module Survey Coding Frequencies for Semester 2 Teaching Script – CB4

Code	Abbreviation	Total Number of Teachers Represented (N = 14)	Percentage of Total Responses (%)
Learning-focused	L-f	13	92.9
Student-focused	S-f	8	57.1
Teaching-focused	T-f	14	100

Most of the teachers (92.9%) demonstrated two of the motivations in their CoRe survey statements, while just over half shared statements that had student-focused motivations. All teachers (N = 14) shared teaching-focused comments. A selection of responses is given below.

- "I learned about misconceptions from the final discussion post and those really made me think about how I teach about entropy." – Teacher 18
- "I have never taught thermochemistry concepts before, so this Teaching Script helped me figure out what my lessons over Gibbs free energy would look like if I ever get to teach that in the future." – Teacher 31
- "Exposure to microstates, following a brief rebellion period of stating I would never touch these, made me want to teach it. I had not been exposed to the

concept and ended up becoming fond of it and seeing the value pedagogically." – Teacher 3

All teachers but one ($N = 13$) also provided statements with motivations focused on their own learning. Some examples are given below.

- "This course has led me to review this information and challenge if there are any misconceptions in my knowledge of this content." – Teacher 5
- "It added significant depth and conceptual interconnections to my content knowledge, and added some important missing pieces that make a lot of the ideas that I was treating as islands into one connected mass." – Teacher 2
- "Previously, I simply considered entropy as 'more' - more disorder, more moles of gas, more movement. Now, after creating this module, I am thinking more carefully about 'why' entropy increases (more microstates) and how to account for that mathematically. I never considered it from that perspective before." – Teacher 17

Just over half of the teachers ($N = 8$) shared statements focused on their own students' learning. A selection of responses is given below.

- "It was challenging to keep the concept at a level that I think my students would understand." – Teacher 22
- "This is hard content, and I would want to make sure I have ways my students can understand the information instead of just see or hear it." – Teacher 6
- "I think each variable is important in its own way, but it shows students that there is a reason to focus on each before focusing on the big picture. I've been trying to get students to see the connections between different topics of chemistry, so

Gibbs free energy would do a better job of overlapping with other topics instead of enthalpy and entropy independently." – Teacher 25

Summary of Module Survey – Teaching Script

The Teaching Script module survey gave participants the opportunity to share their thoughts on their experience completing a Teaching Script in the CHEM 772 course. Through the module assignment, participants expressed positive attitudes toward teaching thermodynamics topics in the future, as well as improvements to their content knowledge and pedagogical skill. Therefore, the Teaching Script module enabled teachers to improve both the quantity and quality of their overall PCK. The main themes from the Teaching Script module survey were:

- It was difficult for teachers to learn, teach, and apply new thermodynamics concepts due to the challenging nature of topics themselves; however, the Teaching Script allowed teachers to reflect on the content and create a lesson that could be used in future teaching. This combination of their KoSc, KoCO, and KoT demonstrated improved PCK quality.
- Although participants noted improvements to their knowledge, skill, and confidence, participants also identified gaps in their content understanding and confidence that could be remedied through more teaching experience and learning. CHEM 772 introduced new knowledge, but some teachers need more time and practice to master their understanding and application of these topics. Through further improvement of their KoSc, teachers have the potential to improve their overall PCK.

- Creating a Teaching Script was an intensive process, but it gave teachers the opportunity to think about their lessons in great detail. Completing the module was an exercise in demonstrating understanding of a challenging topic (KoSc) as well as understanding of how to teach the topic effectively (KoT), which indicated improvements to the quality of their overall PCK.

All participants shared teaching-focused statements, demonstrating that teachers thought about how they could improve their own teaching effectiveness. Almost all teachers shared comments related to their own learning, while just over half responded with student-focused statements. This reveals that participants placed more emphasis on their own learning of thermodynamics content. Like with the CoRe, the CHEM 772 material may have been more challenging for teachers, so their priorities would be mastering the material as learners and teachers before being able to focus on their students.

End-of-Semester Survey

At the end of the Spring 2022 semester, I sent out an email invitation to participants of CHEM 772 and CHEM 778 to complete a survey about their experiences in core MS program courses, and the MS program overall, during the given semester. Responses to this survey were coded with Codebooks 1 and 4.

<u>Codebook 1</u>

Coding frequencies for Codebook 1 can be found in Table 174.

Table 174. End-of-Semester Survey Coding Frequencies for Semester 2 – CB1

Code	**Abbreviation**	**Total Number of Teachers Represented (*N* = 18)**	**Percentage of Total Responses (%)**
Attitudes	A-p	1	5.6
	A-c	9	50
Knowledge	K-c	17	94.4
Skill	S-c	9	50
Teaching	T	14	77.8
Feedback	F	18	100
Modules	M	6	33.3
Interaction	I	13	72.2
Reflection	R	12	66.7

<u>Examples of Attitudes (A-p and A-c)</u>

Half of the teachers (*N* = 9) shared comments related to their current attitudes. One teacher described the impact of their prior experiences and attitudes on their current attitudes toward their own teaching.

- A-p: "My first teaching placement really messed with my confidence as a teacher. I was not nurtured just ridiculed and they made me feel that I was not a real chemistry teacher and that I could never really teach the higher up students since I am 'just good at the general level.'" – Teacher 7

- A-c: “I really hope I have [become a more effective teacher this semester]. I do have doubt, but that might be my own self-doubt…I learned so much and [CHEM 778] got me so motivated to be a better teacher” – Teacher 7

This teacher shared a lack of confidence resulting from a lack of support early in their teaching career. They hoped that they have gained knowledge and skill through the MS program but continued to express “self-doubt.”

Other teachers discussed how the content knowledge they gained through MS program courses has increased their confidence and comfort level with the content itself, as well as with teaching the content.

- “The content course [CHEM 772] helped me feel more confident with teaching thermodynamics.” – Teacher 25
- “It makes me feel more confident when I actually have the information and can explain it.” – Teacher 25
- “I feel more confident teaching [thermodynamics] now.” – Teacher 17
- “I definitely feel much more confident in my ability to use phenomena and modeling.” – Teacher 16
- “I feel more comfortable in modeling, discussions, and creating creative opportunities.” – Teacher 6

Teachers also described feelings of enjoyment related to their time in the program, including positive emotions associated with learning.

- “I loved getting back into learning and calculating and thinking through chemistry.” – Teacher 30

- "Allowing my students to 'explore and play around' as they put it, was re-energizing for me and for them. It was a very pleasant, unexpected result of taking Chem 778" – Teacher 17

Participants also described changes to their motivation, including a more active approach toward changing their teaching practice.

- "My motivation to try new things has also improved." – Teacher 31
- "Not being ok with being complacent is the most important." – Teacher 3

One teacher discussed sadness at their time in the program coming to an end.

- "The teaching class was amazing and makes me really sad that I am almost done with this program." – Teacher 7

<u>Summary of Attitudes (A-p and A-c)</u>

Many teachers discussed their current attitudes after participating in CHEM 772 and/or CHEM 778 during the Spring 2022 semester. The most common themes were:

- Teachers gained confidence in teaching by strengthening their thermodynamics content knowledge and pedagogical knowledge of teaching strategies. Through the two core program courses, teachers were able to develop better PCK by feeling more confident in their ability to explain challenging content.
- The learning that took place in the MS program caused professional reinvigoration for teachers: participants noted increased motivation, reenergization for themselves and their students, and lower complacency. The MS program allowed teachers to reenter the classroom and learn again for themselves, which led to a higher quality of teaching.

- Developing higher quality PCK contributed to teachers' improved confidence teaching chemistry topics, especially through their KoSc and KoT gains through the MS program courses during Semester 2.

Examples of Knowledge (K-c)

All teachers but one ($N = 17$) discussed their current level of knowledge after participating in MS courses this semester. Many teachers described increased content knowledge of thermodynamics after participating in the CHEM 772 course. Some examples are given below.

- "772 gave me a better understanding in thermodynamics." – Teacher 14
- "My background in thermodynamics was very weak, so I learned a lot from Instructor C. A lot of things make sense now." – Teacher 25
- "I really needed to brush up on my Thermodynamics, and I did learn a LOT more than I had previously, so that was very helpful." – Teacher 17
- "I learned more about enthalpy and entropy than I knew before. I recognized some misconceptions I had myself." – Teacher 18
- "The thermodynamics course expanded my prior knowledge and challenged me to understand the concepts." – Teacher 31

Participants expressed feelings of the course having impact on their content knowledge, but not necessarily increasing their content understanding.

- "This course [CHEM 772] gave me a refresher of concepts of thermodynamics, but I do not feel that my understanding of thermodynamics is necessarily any better than when I started." – Teacher 5

- “The thermo course was more of a cementing of my knowledge as opposed to gaining new knowledge. In reality, this meant I could complete it all in a reasonable time frame, but more of a challenge would also have been welcomed.” – Teacher 3

Teachers also described increased levels of pedagogical knowledge after participating in the CHEM 778 course.

- “I learned a lot about teaching from the books and from the other teachers in the program.” – Teacher 20
- “I don't know that my chemistry knowledge has changed, but my knowledge as a teacher certainly has. I feel much more capable of using phenomena and models in my classes now.” – Teacher 16
- “I think I've gained a wider perspective on teaching - how to teach a topic, what to cover, and what the activities/labs/demos are.” – Teacher 25
- “My pedagogical knowledge increased.” – Teacher 6

Summary of Knowledge (K-c)

The Spring 2022 semester was unique because one core course focused on chemistry content and the other focused on pedagogy. Therefore, knowledge gained during this semester had broad implications. The main themes for the knowledge codes were:

- Some teachers recognized weaknesses in their thermodynamics background that were strengthened through participation in CHEM 772. Other participants expressed a desire to have learned more in the course.

- Participants were able to learn about and utilize new chemistry teaching strategies in their classroom, highlighting increased pedagogical knowledge and skill. Thus, CHEM 778 directly impacted participants' teaching effectiveness. Gaining KoT and KoR enabled teachers to develop higher quality PCK through the CHEM 778 course.

Examples of Skill (S-c)

Half of the teachers gave statements related to their current skill level after the Spring 2022 semester. Many teachers discussed how new knowledge and ideas has impacted how they teach their students.

- "The AST text was a catalyst for making significant changes to the way I teach and how students learn in my class… I'm encouraging more student talk and explanation time…I am trying new techniques, I'm learning from those experiences, and growing as a teacher." – Teacher 9
- "I'm more considerate with the types of assignments I make for my students. Instead of just recalling information, I now want students to be able to think through their problems and find a solution. Before, I didn't really have an idea of how to do this, but after taking CHEM 778, I have several ideas that other teachers have done or come up that I could use." – Teacher 25
- "I plan to add more about work into my explanations of thermodynamics, so students can better understand the concepts." – Teacher 22
- "I am finding that I think through how I will present material more deeply. I am taking a fresh look at my curriculum and trying to find areas where I can do a better job of explaining, demonstrating, or letting the students 'discover'

something with guidance from me. I am trying to be more of a facilitator of learning not a creator of lesson plans." – Teacher 17

Teachers also reflected on skills they have gained that have had professional impacts.

- "I think I have improved my skills this year and I have as a teacher been challenging myself to get better and better with the new skills I have learned." – Teacher 7
- "I also learned how to ScreenCast, which is a new skill for me that I will use going forward for feedback and also homework." – Teacher 30
- "I know so much more now that I can answer almost any question in class and I can help other teachers understand the content as well." – Teacher 16

Some teachers provided less detailed responses to survey questions. When asked how their pedagogical skill had changed this semester, one teacher said "a lot" (Teacher 29), while another said "none" (Teacher 23).

Summary of Skill (S-c)

Many teachers described changes to their skill after their experience in the program this semester. The most common themes in responses related to skill were:

- Participants experienced improvements to their pedagogical skill by implementing new teaching strategies and frameworks that they learned in CHEM 778.
- Teachers were better able to explain content, demonstrating increased PCK by combining content and pedagogical knowledge bases.

<u>Examples of Teaching (T)</u>

Most teachers (77.8%) shared comments related to their own teaching. Multiple participants discussed how the chemistry teaching strategies course gave them ideas to implement in their own teaching. A selection of responses is given below.

- “The Teaching Strategies course introduced me to a wide variety of teaching strategies and ideas that could apply to any class... I have started thinking about ways I can implement creativity throughout my lessons.” – Teacher 31
- “I feel much more capable of using phenomena and models in my classes now.” – Teacher 16
- “I introduced some new ideas (labs) because of discussions in 778.” – Teacher 1
- “I think more about how to create opportunities for students to be creative.” – Teacher 20

Teachers also described how their teaching has been transformed through their experience in the MS program, including how they hope to change for the future. Some examples are given below.

- “I now have a stronger imperative for including creativity as an aspect of all of my classes, but mostly for chemistry.” – Teacher 3
- “After going through the book, the discussions, and the project, I can honestly say that it has and will continue to transform my teaching.” – Teacher 17
- “I also feel that I have more tools and a focused goal next year to improve with my students.” – Teacher 7
- “I felt 778 gave me the most benefit in learning how to grow as an educator.” – Teacher 14

Summary of Teaching (T)

Participants discussed the impacts of the MS program courses on their teaching. The main themes were:

- Teachers utilized new content (KoSc) and pedagogical (KoT) knowledge in their classroom, demonstrating how their learning in the MS program has influenced their teaching effectiveness. Developing these knowledge bases contributed to their development of higher quality PCK.
- Teachers also described how they hope to make changes to their teaching in the future, which reveals participants' desire for professional growth. The MS program gives teachers an opportunity to reach goals.

Feedback (F)

Data coded as feedback was sent directly to MS program instructors.

Modules (M)

A third of the participants (*N* = 6) gave comments related to the CoRe and Teaching Script module assignments. Four participants discussed how the modules allowed them to apply new knowledge to their teaching.

- "As a teacher, I found anything related to teaching the material to be most meaningful to me - so that was most often seen in the …Teaching Script." – Teacher 25
- "I found…Teaching Script/CoRe to be helpful in thinking through the teaching aspect of the content." – Teacher 30

- “The CoRe and Teaching Script forced me to think about the concepts I learned in this class and develop a lesson that is appropriate for my high school students.” – Teacher 31
- “I really do appreciate the CoRe and Teaching Script assignments because they made me think about how to apply what I had learned to my own teaching.” – Teacher 17

Two teacher comments suggested that the module assignments had a lack of meaning for them.

- “The CoRe [and] Teaching Script seemed like 'busy work' to be honest.” – Teacher 16
- “I like the CoRe assignments, but the Teaching Script is kind of pointless.” – Teacher 6

Based on participant feedback, there was a split between those who found it meaningful to apply new content to a teaching context and those who found it to be “busy work.”

Examples of Interaction (I)

A majority of participants (72.2%) discussed interactions that took place in the MS program. Many teachers described the impact of interacting with other teachers in the MS program.

- “I think interacting with other teachers about instructional resources and curriculum ideas” was meaningful. – Teacher 6
- “I enjoyed hearing from other teachers and get advice about teaching different concepts.” – Teacher 22

- “The sharing of ideas and troubleshooting them with peers was the most valuable part of this class [CHEM 778].” – Teacher 17
- “I learned a lot about teaching from…the other teachers in the program.” – Teacher 20
- “Again, the chance to share out ideas with so many impressive and passionate colleagues was a joy. It's like having a team of all-stars at a wide array of experience as professionals all within ‘my own science department.’” – Teacher 2

Several teachers discussed the impact of interacting with other teachers during the CHEM 778 Zoom meetings.

- “The Tuesday night Zoom meetings for 778…really reminded me on a valuable routine pattern that there was a group of others out there working through the same trenches and expectations as I was, and it was really helpful to keep my personal energy high.” – Teacher 2
- “Chem 778…had engaging Zoom discussions that allowed me to interact with other teachers grappling with the concepts presented in Ambitious Science Teaching and Developing Creativity.” – Teacher 9
- “I really liked the…Zoom sessions we did. It was nice to see everyone and have a chance to collaborate/bounce ideas off of each other.” – Teacher 16
- “I also learned several new lab ideas and teaching strategies from other teachers in the discussion boards and zoom meetings throughout the course [CHEM 778].” – Teacher 31

Two teachers also discussed the interactions they experienced through the Sharing Project, an assignment through which two teachers involved their students in a collaborative project in which data was shared across classrooms.

- "I grew a lot from my work on the Sharing Project and having that prompt and structure to work with a colleague in a new and challenging way - compared to the usual work of collaborating with someone next door or down the hall at school." – Teacher 2
- "I really enjoyed working with another teacher for the sharing project. It was fun to learn from them and have our students collaborate." – Teacher 20

Ten teachers (55.6%) discussed what they gained this semester other than chemistry content knowledge and pedagogical skill. A selection of responses is given below.

- "I gained collegial connections with other chemistry educators." – Teacher 23
- "Camaraderie with peers who also want to be better chemistry teachers. I feel like I have a new network of teachers that I can tap into when I am struggling with ideas for how to teach a concept." – Teacher 17
- "Reassurance that other teachers are experiencing some of the same things as me, even though we live in different states and teach in different districts (behaviors, student motivation, willingness to try new things, cooperative and uncooperative coworkers, etc.)." – Teacher 31

One participant specifically discussed interactions with the MS program instructors.

- "Courses provided meaningful interaction with faculty." – Teacher 9

One teacher shared their anticipation for meeting MS program participants in person over the summer session.

- "I'm just excited to finally meet everyone in person. The zoom meetings have been nice because I can now place a face to a name, but really, I can't wait to be in-person, even if it's just for 2 weeks." – Teacher 25

Summary of Interaction (I)

In the end-of-semester survey, many participants highlighted the significance of interactions with peers and faculty for the MS program. The most common themes related to interactions were:

- Participants gained ideas from other teachers regarding instructional materials and teaching strategies, showing how participants experience professional development by collaborating with their peers in the MS program.
- Interacting with peers and faculty through Zoom discussions was meaningful for teachers' learning.
- Teachers created a professional support network with other MS program participants, highlighting their desire to collaborate and empathize with peers. Having a support network allows participants to continue to grow outside the bounds of the program itself.
- Gaining KoR and KoT from fellow MS program participants allowed teachers to further develop their PCK.

Examples of Reflection (R)

The End-of-Semester survey allowed teachers to reflect on their experience in the MS program over the Spring 2022 semester. Many teachers shared thoughts on how they have taken time to reflect on their teaching and learning.

- "I think for me I do not give myself enough time for reflection. By giving myself time and space for reflection, it was easier for me to try to implement content learned or different teaching strategies. Allowing me to try and do some of the things necessary try to grow as a teacher are super valuable." – Teacher 7
- They have gained "a fresh perspective on teaching and an increased understanding of my need for reflection." – Teacher 3
- "I also used the research class to reflect on the year and figure out what I wanted to do." – Teacher 6
- "I am finding that I think through how I will present material more deeply." – Teacher 17

Teachers also reflected on the value of participating in the MS program from a financial perspective.

- "College is expensive. I was happy to pay in order to get the credit and learn the material, but it's just expensive." – Teacher 30
- "As I am working towards my master's degree, it will lead to a pay raise, which gives value to each class I take." – Teacher 5
- "I feel…that my money was worth it." – Teacher 20

Participants thought deeply about how to incorporate new strategies and knowledge into their teaching.

- "The critical examining of my practice while also applying new content has been the hallmark of this program in general." – Teacher 3
- "The courses are rigorous and focus on content that is necessary to be an excellent teacher of chemistry." – Teacher 17

- "I have ideas that I want to implement in the future, which gives me a goal to work towards." – Teacher 31
- "I have put more thought into how I would teach these tougher concepts and get students to understand these more abstract concepts." – Teacher 5
- "I have been more thoughtful about the effects of what I am doing in class." – Teacher 14
- "I think more about how to create opportunities for students to be creative." – Teacher 20
- "This program has a been a great way for me to better myself. I just hope I can." – Teacher 7

There were also general reflective comments from teachers that related to their own personal teaching and learning experiences. Teachers' reflections demonstrated their PCK through their combination of multiple knowledge bases. A selection of responses is given below.

- "It is one level of understanding to be able to do problems yourself. A higher level of understanding is required to explain a concept at a student appropriate level." – Teacher 17
- This teacher gained "respect for other teachers and schools. Reading what other teachers go through, it makes me feel very fortunate the support and resources I have at the school I teach at. Because of this, I try to be more patient with my students because they honestly have the ideal size and length of class. They don't have to deal with state testing, and because of that, we end up having a lot of time

that other schools don't have. I don't have the problems other teachers have and it's just been a humbling experience." – Teacher 25

- "I'm also experiencing life as a student. This makes me more relatable to my students." – Teacher 9

Summary of Reflection (R)

Teachers shared reflective thoughts in the end-of-semester survey related to their experience in program courses and personal thoughts related to teaching. The main themes related to reflection were:

- Teachers recognize that reflection is an important process for making decisions about what and how to teach, which connects to teachers' KoCO. The act of reflecting on their teaching allowed teachers to improve the quality of their PCK.
- Participants felt that participating in the MS program had high value for money, indicating that the value of learning chemistry and pedagogical content outweighed the cost of the courses.
- Teachers have taken time to reflect on how to bring new knowledge into their classrooms. The MS program allowed participants to gain new knowledge and think about how they would apply this new knowledge to their instruction. Teachers combined their KoSc and KoT, demonstrating the development of higher quality PCK. The MS program itself was a means through which professional development could take place.

Codebook 4

Codebook 4 was then used to analyze participants' motivations for statements made in the end-of-semester survey. Coding frequencies can be found in Table 175.

Table 175. End-of-Semester Survey Coding Frequencies for Semester 2 – CB4

Code	**Abbreviation**	**Total Number of Teachers Represented (*N* = 18)**	**Percentage of Total Responses (%)**
Learning-focused	L-f	17	94.4
Student-focused	S-f	9	50
Teaching-focused	T-f	16	88.9

Most teachers described motivations focused on learning (94.4%) or teaching (88.9%). Half of the participants (*N* = 9) shared student-focused statements. When reflecting on their experience in the MS program over the Fall 2021 semester, most participants shared sources of motivation related to their own learning. Some examples are given below.

- "I really needed to brush up on my Thermodynamics, and I did learn a LOT more than I had previously, so that was very helpful." – Teacher 17
- "I don't know that my chemistry knowledge has changed, but my knowledge as a teacher certainly has. I feel much more capable of using phenomena and models in my classes now." – Teacher 16
- "I learned more about thermodynamics, particularly related to the math involved." – Teacher 18

Many participants also shared statements focused on their teaching. A selection of responses is given below.

- "As a teacher, I found anything related to teaching the material to be most meaningful to me - so that was most often seen in sharing teaching experiences in the discussion forums and the different projects (sharing and creativity, Teaching Script). The content course helped me feel more confident with teaching thermodynamics." – Teacher 25
- "The creativity and sharing project were nice because I could immediately implement them in my classes. They directly affected my lessons and I plan to keep using the creativity project in the future. I also hope to expand on it by adding more creativity projects to my other classes." – Teacher 31
- "I think I have improved my skills this year and I have as a teacher been challenging myself to get better and better with the new skills I have learned." – Teacher 7

Half of the participants discussed their experiences in the program in terms of their own students' learning. Some examples are given below.

- "The AST text was a catalyst for making significant changes to…how students learn in my class." – Teacher 9
- "I think more about how to create opportunities for students to be creative." – Teacher 20
- "Some of [the assignments] forced me to think about how to teach concepts I don't normally teach in a way that makes sense to my students." – Teacher 31

Summary of End-of-Semester Survey

Eighteen participants completed the end-of-semester survey, which asked them to reflect on their experience in the MS program during the Spring 2022 semester. Teachers described increased confidence in their ability to explain thermodynamics content, which points to increased content and pedagogical knowledge. These improvements to their KoSc and KoT indicate improved PCK. CHEM 778 allowed teachers to gain new chemistry teaching strategies, which they then implemented in their own classrooms, demonstrating increased pedagogical skill and KoT as a component of their PCK. Interactions with peers and faculty were meaningful for teachers. Program participants created a support network with one another, which allowed for deeper PCK and professional development. Most teachers shared learner- and teaching-focused motivations regarding their Spring 2022 experience. Half of the participants shared student-focused statements. The most common themes from the end-of-semester survey were:

- The Spring 2022 core courses focused on thermodynamics content and chemistry teaching strategies and allowed teachers to develop knowledge and skills that directly improved their PCK. In addition, teachers demonstrated increased confidence in teaching chemistry content. By combining their KoSc and KoT, teachers demonstrated improved PCK quality. The MS program supported participants' ability to teach more effectively by improving their KoT as a component of their overall PCK.
- The interpersonal interactions between MS program participants continued to be meaningful and allowed teachers to create a learning community amongst

themselves. The support network that participants created allowed teachers to learn and grow independent from the MS program. These interactions supported participants' PCK and professional development.

- CHEM 778 exposed participants to new chemistry teaching strategies, which prompted teachers to reflect on their current teaching methods and assess how they want to grow and improve for their future students. By increasing their KoT, the CHEM 778 course supported PCK development.

Summary of Semester 2

During Semester 2 of data collection, methods included the CoRe module and its survey, the CHEM 778 midway course reflection, the Teaching Script module and its survey, and the end-of-semester survey. The main themes for Semester 2 were:

- Teachers developed chemistry content knowledge (KoSc) through the CHEM 772 course that they applied to their teaching through the CoRe and Teaching Script module assignments. By applying their thermodynamics knowledge to a teaching context, they demonstrated and combined all PCK components to reveal higher quality PCK. Although the topics were difficult for teachers to learn, teach, and apply, the modules allowed participants to develop stronger PCK. Teachers noted gaps in their content knowledge that persisted after the CHEM 772 course, which indicated a need for future KoSc growth.
- Through the modules, teachers reflected on their current instruction of CHEM 772 topics and applied new knowledge gained in the MS program (KoSc) to their teaching. By combining their KoSc and KoT, teachers demonstrated improved PCK quality. The modules also allowed teachers to take students' prior

knowledge into account when designing thermodynamics lessons. The modules enabled teachers to combine their KoSc, KoSt, KoCO, and KoT, which demonstrated improvements to the quality of their overall PCK.

- Teachers' module assignments were more detailed, focused, and reflective in Semester 2, revealing improvements to participants' PCK through improved connections between their KoSc and KoT. This combination of knowledge bases indicated improved PCK quality.
- Teachers demonstrated improved confidence in their thermodynamics content knowledge (KoSc), as well as their confidence teaching these topics (KoT), which reveals the positive impact of the CHEM 772 course on participants' PCK.
- The CHEM 778 course enabled participants to reflect on their current teaching practice and develop new KoT and KoR, which led to improved PCK. Teachers were willing to make changes to their teaching through CHEM 778 assignments, which led to the MS program's direct impact on its participants' instruction.
- Interactions between MS program participants were meaningful for teacher learning and professional development and allowed for improvements to their PCK.

Summer 1

During the first summer session, program participants took part in a course that involved coming to the SDSU campus for a two-week session. This course, CHEM 776, focused on the development of laboratory activities in conjunction with a laboratory research experience with SDSU research faculty and graduate students. Other courses were also available to the MS participants related to waste disposal, green chemistry, and chemical demonstrations. These courses extended past the on-campus segment; however, most of the data collection focused on the on-campus experience. Table 176 discusses the methods used during the summer session.

Table 176. Summer 1 Data Collection Methods

Term	**Data Collection Methods**	**ID Codes**
Summer 1	**Before campus:**	
	ASCI (pre)	ASCI
	Summer Journal #1	SJ
	On campus:	
	Summer Journal #2	SJ
	After campus:	
	Summer Journal #3	SJ
	ASCI (post)	ASCI
	Post-campus summer survey	PCSS
	End-of-summer survey	EOS
	GTA survey	TA

ASCI (pre/post)

Three participants, excluding the narrative participant, completed both the pre- and post-test of the ASCI. Pre/post data are displayed in Table 177. According to Bauer, the percentage scale indicates the level of the given category that a participant has with respect to Chemistry Laboratory Research, in our case.[64] The categories of attitudes in the inventory include emotional satisfaction, anxiety, intellectual accessibility, interest & utility, and fear.[64] Bauer indicates that a higher score or percentage indicates a higher degree of the attitude; for example, a higher score for anxiety indicates more anxiety and a higher score for emotional satisfaction indicates higher emotional satisfaction.[64]

Table 177. MS Program Participant ASCI Pre/Post Data for Summer 1

Participant Code		Emotional Satisfaction (%)	Anxiety (%)	Intellectual Accessibility (%)	Interest & Utility (%)	Fear (%)
1	Pre	88	53	37	100	50
	Post	71	50	37	90	50
2	Pre	42	60	50	70	83
	Post	92	23	43	97	0
3	Pre	50	67	46	67	50
	Post	42	73	47	63	83

Taking these clarifications into account, we would hope to see an increase in emotional satisfaction, intellectual accessibility, and interest & utility; conversely, we would hope to see a decrease in the teachers' anxiety and fear surrounding chemistry laboratory research.

For emotional satisfaction, participants 1 and 3 experienced a decrease in emotional satisfaction, while participant 2 became more emotionally satisfied with chemistry laboratory research after the 2-week research experience. A *t*-test indicated that these changes were statistically insignificant (p = 0.7298).

In terms of anxiety, participants 1 and 2 experienced less anxiety after the two-week experience, while participant 3 experienced a small increase in anxiety. A *t*-test indicated that these changes were statistically insignificant (p = 0.4780).

For intellectual accessibility, all three participants stayed the same or experienced small changes after the research experience. A *t*-test indicated that these changes were statistically insignificant (p = 0.5101).

In terms of interest & utility of chemistry laboratory research, participants 1 and 3 experienced small decreases and participant 2 experienced a 27% shift toward higher interest and utility. A *t*-test indicated that these changes were statistically insignificant (p = 0.7418).

The data for fear indicates that participant 1 remained the same at 50%. Participant 2 decreased to 0% fear, whereas participant 3 became 33% more fearful of chemistry laboratory research after the summer experience. However, these results were also statistically insignificant (p = 0.6768).

Summer Journals

Participants involved in the summer session were invited to complete three guided summer journals surrounding their on-campus experience at SDSU. Each of the summer journals was coded using Codebooks 1 and 3, when applicable.

Summer Journal #1

The first journal was prompted prior to teachers arriving on campus and focused on their goals for the experience, both as a teacher and as a scientist, and what they anticipate the experience to be like.

Codebook 1

Coding frequencies for Codebook 1 are presented in Table 178.

Table 178. Summer Journal #1 Coding Frequencies for Summer 1 – CB1

Code	**Abbreviation**	**Total Number of Teachers Represented (N = 7)**	**Percentage of Total Responses (%)**
Attitudes	A-p	6	85.7
Goals	G	7	100
Background	B	1	14.3
Interaction	I	1	14.3
Reflection	R	7	100

Goals

Before arrival, all seven program participants shared their goals for the campus experience. Four of the teachers mentioned having goals for interacting with and building relationships with colleagues and mentors throughout the on-campus experience. Teachers hoped for professional development opportunities through interactions with other MS program participants while on campus.

- “I hope to get to know my cohort colleagues better and grow in those opportunities for some networking and professional connections that might last for years to come. I'm hoping to establish a good relationship with [SDSU professor] as my cooperating research lead.” – Teacher 2
- “To engage in fellow students about teaching strategies.” – Teacher 7
- “Create relationships with colleagues.” – Teacher 6
- “Learn from fellow teachers.” – Teacher 1

One teacher shared a goal related to the demonstrations course.

- “To get a hands-on experience doing demos [and] to be comfortable doing demos.” – Teacher 7

Six of the teachers discussed goals related to graduate-level chemistry research in the SDSU labs.

- “I’m hoping to…get a much better sense of how research works at the university level, not having done formal research of my own as an undergrad (which was so many years ago anyway!).” – Teacher 2
- “I have a goal to gain a better understanding of certain higher-level lab technologies/procedures, such as NMR or Western Blot.” – Teacher 5
- “Experience graduate level research in chemistry” – Teacher 6
- “Participate in research [and] review use of analytical machines,” – Teacher 4
- “Learn a lot about ice cores.” – Teacher 3
- “Experience research projects.” – Teacher 1

Five teachers mentioned goals for making progress toward the action research component of the MS degree. Planning their workload indicates improvements to their time management skills and may indicate professional development.

- “I'm hoping to move forward with my planning and preparations for my research that is set to start this coming fall back in my classroom through some refining work with Instructor B and Instructor A.” – Teacher 2
- “To hammer out my research and my defense.” – Teacher 7
- “To finalize my research project fully” – Teacher 6
- “Prepare materials for action research” – Teacher 4
- “Also get all of the work done that I have ahead of me…” – Teacher 3

Three teachers mentioned a goal for developing resources or preparing information to bring back into their own classrooms. This goal relates to teachers’ KoCO and KoR, which demonstrates goals for improving their PCK.

- “I also have a goal to develop 3 ideas of inquiry labs that I can use in my classroom this upcoming year.” – Teacher 5
- “Learn a lot about…how I could bring some of these concepts into the tangible in my classroom” – Teacher 3
- “Take back information for my students about research.” – Teacher 1

Upon reflecting on goals that participants had for the summer as scientists, six of the seven teachers discussed their current research skill level and what they hope to gain through their work in a research laboratory.

- "I hope this experience will deepen my own validity as a researcher personally, as formal research just doesn't happen in my world as a full-time teacher." – Teacher 2
- "I just want to know more about how analytical work is done in a climate laboratory and have some good experiences to share with friends, colleagues, and anyone who will and wants to listen." – Teacher 3
- "As a scientist I am excited to look at different tools/strategies we use in the chemistry lab." – Teacher 7
- "I hope to gain a better understanding of the research process and about organic chemistry, which is what our research project is about." – Teacher 5
- "More technical lab experience." – Teacher 4

When discussing their goals for laboratory research, Teacher 1 provided details regarding their educational background.

- "The college I went to was not a research facility so I will enjoy getting to do the research and learning more about climate science." – Teacher 1

Six of the seven teachers also discussed their goals for the summer experience as teachers, specifically related to bringing new knowledge and resources back into their classrooms that were gained through program courses and interactions with other teachers. These goals indicate KoCO, KoSc, and KoR, which demonstrate their goals to improve their overall PCK through the two-week campus experience.

- "I hope that my research experiences this summer can lend some more personal, authentic examples to my toolbox that I can use to engage and inform students about what chemistry undergrads might experience and what opportunities there are in that field as they choose their paths for after high school." – Teacher 2

- "I want to be able to make digestible the research of academics at universities and also make it seem attainable in some way to the secondary student." – Teacher 3
- "I am excited about learning different teaching strategies. Looking into different perspectives on teaching and seeing if I can adapt them in my classroom." – Teacher 7
- "I hope to collect ideas for classroom activities." – Teacher 5
- "I hope to be able to collaborate and gain information from like-minded and not like-minded teachers." – Teacher 6

Teacher 1 reflected on the value of these interactions for professional development.

- "I think the group meetings with the other teachers are vital to help you grow as a teacher. Bouncing ideas off each other of what works in your classroom etc. is a growing opportunity." – Teacher 1

<u>Summary of Goals</u>

Teachers shared their goals for the summer campus experience, which mainly focused on the following themes:

- Teachers hoped to develop professional connections with other MS program participants. They also expressed that these interactions allowed them to experience professional development, which may indicate potential improvements to their PCK. Teachers hoped to bring back new KoR gained through these interactions back to their classrooms, which indicates their desire to improve their overall PCK. By describing these goals, teachers also demonstrated their KoG, KoCO, and KoSt, which demonstrated their current level of PCK.

- Participants hoped to gain a better understanding of chemistry laboratory research at the graduate level by gaining new laboratory skills and knowledge of instrumentation. Teachers also discussed bringing back practical knowledge and skills to implement into their own laboratory instruction. This demonstrates teachers' desire to develop PCK through the summer experience through the application of new KoSc to their teaching.
- Teachers hoped to make progress toward their action research projects for the MS program.

Reflection

Teachers were then asked to reflect upon their upcoming campus experience. For teachers who are returning to campus for their second summer, their reflection focused on their past experience on campus.

- "This is my 2nd year and I am more comfortable with what I am about to get into. Instead of worrying about what it will be like procedurally and logistically I am already focused on the science I will be engaging in. I feel like I am at least 1-2 days ahead in terms of thinking about the experience as to where I was last year. I also now know that the days will be long and full and I just need to accept that which I am hoping will improve my disposition as I tire in the waning hours while there are still cool things going on!" – Teacher 3
- "I think I know a little more about what to expect when it comes to the expectations of the classes from the education portion of my casework. I am

still unsure of how my lab experience will be since I know from last year the lab experiences vary from lab assignment to lab assignment. I also do not know what my expectations of my research are since this is very different from last year's class." – Teacher 7

- "I really enjoyed my time last summer at SDSU. I thought the professor and TA in my department did an excellent job of informing us and allowing us to participate in their lab." – Teacher 1

For new teachers, they shared what they anticipate the research experience will be like in an SDSU lab.

- "I guess I'm really unsure about what to expect as a first-time on-campus student in the program. Hearing from others throughout the past year and then more consistently this summer in our meetings and in discussion posts, I am curious as to how my own experience will compare as I don't have any TAs in the lab to my knowledge and will be working with [research professor] directly on my own and not part of a subgroup from within the summer on-campus group. My initial meeting with him was great, and he seems to be a very passionate and relatable man and scientist, so I think it will be very positive and challenging and rewarding. I am somewhat more at ease just because I've been teaching for 21 years and my content knowledge is far stronger than it would have been if I'd worked in this program as a much less seasoned teacher." – Teacher 2
- "I imagine that my lab experience will look very different than my undergraduate lab experience. I feel that there will be more emphasis on

literature as ‘background information’ instead of just having to read a paragraph or two. I imagine that lab procedures will take much longer than just 3 hours like they did in undergraduate, and that you may be running several different procedures at one time, rather than just focusing on one.” – Teacher 5

- “I'm a bit nervous because it's been so long since being in a college chemistry lab and I may be missing or have forgotten some skills but I imagine this is common and they are prepared for it.” – Teacher 4
- “I have been in the lab in undergrad, since we are hoping on a project instead of having our own I will be interested to see the role we are given in the research.” – Teacher 6

Summary of Reflection

Teachers reflected on their upcoming campus experience, with returning participants focusing on the impact of their past experience. The main themes for reflection were:

- Teachers returning to campus for their second summer knew what to expect in terms of obligations but reflected that their lab experience may differ based on their lab assignments.
- New teachers reflected on their past laboratory research experiences and discussed skills and knowledge they would develop during the two-week campus experience. These teachers also shared their expectations for their time in the SDSU research labs.

Attitudes (A-p)

To conclude the first summer journal entry, teachers were asked to share any other thoughts or feelings they had leading up to being on campus. All teachers shared attitudes they held prior to the research experience. Three teachers discussed feelings of excitement.

- "I'm really excited about being immersed in this work for the two weeks on campus and being able to focus on it with all of my daily time and energy rather than trying to fit it my work among the commitments and demands of being a full-time teacher and also a husband and father…I am excited to be a student with this level of focus and intensity. I always relish extended opportunities for this kind of PD and work professionally, and I intend to squeeze out every last drop of this experience." – Teacher 2
- "I am overall excited to learn and become a better science teacher." – Teacher 7
- "I am excited to experience the research process and see what research looks like in a wet lab" – Teacher 5

Two teachers shared feelings of concern or worry.

- "I am a bit concerned that I will not be competent enough to fully understand the research that is being conducted." – Teacher 5
- "That my research is not good enough, that I am not good enough for the program and will not offer enough for students. Of students isolating me. A lot of this is due to my mental (cognitive) disability and social anxiety. I recognize this but still am trying to deal with it." – Teacher 7

Four teachers identified difficult or stressful aspects of the on-campus component or the program overall.

- "The program has been good, a little intense at times while being a full-time teacher, but I expected some of that since it is a Master of Science instead of a Master's of Ed." – Teacher 6
- "I both accept and am worried about the workload. Granted much of this could have been done in the past weeks, but here I am with a mountain of work ahead of me and there is some dread. At the same time this will likely be the last major classes I ever take and as a result I am trying to savor even the stressful moments because that is one of the aspects of being a student." – Teacher 3
- "Mainly just logistics, finding my way around, making sure I have everything I need, may also be dealing with family situations that could make my time more difficult." – Teacher 4
- "I will miss my family." – Teacher 2

<u>Summary of Attitudes (A-p)</u>

Teachers shared their attitudes prior to arriving on campus for the two-week experience. The main themes for prior attitudes were:

- Teachers were excited to learn, participate in laboratory research, and bring their experience back to their classrooms.
- Teachers expressed worry that they would not be able to succeed in the research labs due to a lack of prior skill, knowledge, or confidence.

- Participants discussed the challenges associated with the on-campus experience, including the difficulty of the workload and spending time away from family.

Codebook 4

Codebook 4 then allowed me to break down the teacher statements by source of motivation. Each comment was assessed to determine the focus of the comment, either focused on the participant's learning, their students' learning, or the participant's teaching. Coding frequencies are displayed in Table 179.

Table 179. Summer Journal #1 Coding Frequencies for Summer 1 – CB4

Code	**Abbreviation**	**Total Number of Teachers Represented (*N* = 7)**	**Percentage of Total Responses (%)**
Learning-focused	L-f	7	100
Student-focused	S-f	3	42.9
Teaching-focused	T-f	5	71.4

All participants shared learning-focused statements. Most expressed teaching-focused motivations (*N* = 5) and three of the seven teachers discussed student-focused motivations. Because the first journal focused on teachers' expectations for the campus experience, many focused on their own learning. Some examples of teacher statements are below.

- "I have a goal to gain a better understanding of certain higher-level lab technologies/procedures, such as NMR or Western Blot." – Teacher 5
- "Learn a lot about ice cores." – Teacher 3
- "The college I went to was not a research facility so I will enjoy getting to do the research and learning more about climate science." – Teacher 1

The next most common motivation was focused on teaching. A selection of teacher responses is below.

- "I also have a goal to develop 3 ideas of inquiry labs that I can use in my classroom this upcoming year." – Teacher 5
- "I am overall excited to…become a better science teacher." – Teacher 7
- "As a teacher I hope to be able to collaborate and gain information from like-minded and not like-minded teachers." – Teacher 6

Teachers also shared student-focused motivations. Examples of student-focused statements are given below.

- "I hope that my research experiences this summer can lend some more personal, authentic examples to my toolbox that I can use to engage and inform students about what chemistry undergrads might experience and what opportunities there are in that field as they choose their paths for after high school." – Teacher 2
- "Take back information for my students about research." – Teacher 1

- "As a teacher I want to be able to make digestible the research of academics at universities and also make it seem attainable in some way to the secondary student." – Teacher 3

<u>Summary of Summer Journal #1</u>

In the first journal entry, all seven teachers discussed their attitudes prior to coming to campus, goals for the summer experience, and a reflection on past summer experiences or their upcoming time on campus. The main themes from Summer Journal #1 were:

- Most teachers (85.7%) discussed how their time in the research labs will impact future teaching. This reveals that participants' goals for the summer research experience related to takeaways they planned to bring into their classrooms, which means that teachers intended for the campus research experience to transform their teaching in addition to gaining new lab skills. Teachers' goals for the campus experience revealed their desire to improve their KoCO, KoR, and KoSc, which indicates potential PCK development through the summer component of the MS program.
- Teachers hoped that the summer experience would allow them to form connections with SDSU faculty and graduate students, as well as with fellow teachers in the program with whom they could exchange knowledge of teaching strategies and activities. Teachers hoped to gain KoR and KoT through these interactions, which would improve their overall PCK. Interactions with MS program participants, SDSU faculty, and graduate students supported teachers' PCK and professional development. Teachers' goals related to their roles as

scientists and as educators, showing how the MS program allows growth in both areas.

- Participants described mixed emotions with coming to campus, including excitement for what they hoped to learn, uncertainty about their capabilities, and feelings about personal circumstances. Coming to campus caused complications for many teachers, but these were outweighed by participants' desire to gain laboratory research experience and interact with peers and faculty in person.

In their responses to the first journal, most teachers gave statements focused on their own learning and teaching, with only a few focusing on how their experience will impact their own students' learning.

Summer Journal #2

The second summer journal was prompted after the teachers had spent one full week on campus. The journal asked teachers to reflect on their experience in their assigned research lab, as well as the summer courses.

Codebook 1

Coding frequencies for Codebook 1 are shown in Table 180.

Table 180. Summer Journal #2 Coding Frequencies for Summer 1 – CB1

Code	**Abbreviation**	**Total Number of Teachers Represented (*N* = 5)**	**Percentage of Total Responses (%)**
Attitudes	A-c	2	40
Knowledge	K-c	2	40

Skill	S-c	2	40
Teaching	T	3	60
Feedback	F	5	100
Interaction	I	2	40
Experience	E	5	100
Reflection	R	5	100

Experience

All five teachers shared their experience from their first week in an SDSU research lab.

- "It is good, sometimes it feels like our person isn't prepared for us, but he has kept us busy and showed us some cool processes. We have learned a lot about different things that go on in an organic lab. It has been a good refresher. I kind of expected to jump in on their research and help them but instead we are doing our own mini projects and running tests on what we made. He has shown us his research, but we have not done anything to 'help' him with it." – Teacher 6
- "It was good. My student was very nice and I feel that I have a much better understanding of the instrumentation." – Teacher 4
- "It is awesome, but for different reasons than some. I was here last year so I know a little of what to expect. Also, as a 2nd year and a procrastinator I have a ton of work to do and so not having an 6-8 hour agenda each day is a good thing. We do have work to do and we are learning things, but the pace is a little less than what it was last year for me." – Teacher 3

- “Although there is pressure to do the procedures with the utmost accuracy and attention to detail, I have found that I am a lot more capable of doing the procedures than anticipated. I have surprised myself by understanding what our graduate assistant is talking about when talking about the concepts behind the procedures.” – Teacher 5
- “Learning a lot about the use of ice cores (in different areas of science).” – Teacher 1

Attitudes (A-c)

One teacher shared a shift in attitude because of their involvement in lab research.

- “As a scientist, this has given me greater confidence in my abilities as a researcher if I ever decide to leave the teaching profession.” – Teacher 5

Skill (S-c)

Two teachers shared skills they have developed during the first week of being in the lab.

- “As a scientist this has helped introduce me to procedures and equipment that I had forgotten about, or never done before. I feel like my personal lab skills have been improved.” – Teacher 6
- “Review of instrumentation and experience with a lab has been really cool” – Teacher 4

Teaching

Experience in a research lab has also impacted 60% of the responding teachers in terms of their teaching.

- "I feel that this gives me more of an appreciation for lab procedures to the classroom and can help me implement a more authentic research experience for my students." – Teacher 5
- "I will be able to bring back a lab that I've wanted to develop but didn't have time before." – Teacher 4
- "It will allow me to discuss some cross-curricular items in my classroom. Ex. history and science." – Teacher 1

Knowledge (K-c)

Two teachers discussed knowledge they gained after one week in the research lab.

- "I feel that it has given me more of an understanding towards the research process." – Teacher 5
- "As a scientist, the science of ice cores is blowing my fragile little mind...awesome." – Teacher 3

Reflection

Through their responses to the journal questions, two teachers talked about how the summer research experience has allowed them to reflect on the research process, connecting to their own action research.

- "I have enjoyed seeing things through the eyes of someone in research and academia. We have had lots of philosophical discussions that have helped me get feedback from a different viewpoint." – Teacher 6
- "The researcher side of thing this summer is coming from both the lab I am working in and the research I am compiling from my own project. That aspect

has given me a new and interesting perspective and I am looking at the research lab in similar ways to my own research." – Teacher 3

In the second journal entry, participants were asked to discuss how the summer courses have been meaningful for them. Although all five teachers shared course feedback, two participants also reflected on the impact of the courses so far.

- "The lab experience has allowed me to think of labs from a different perspective and make some connections that I wouldn't have on my own." – Teacher 4
- "I feel that this experience has given me greater motivation to be a research scientist. I have gathered ideas for my own chemistry education research for when I take 777 and 788, and I feel more competent as a chemistry researcher." – Teacher 5

Interaction and Attitudes (A-c)

To conclude the second journal entry, teachers were given the opportunity to share any additional thoughts, feelings, or concerns after spending their first week on campus. Three teachers shared feedback about the summer component of the program, while one participant discussed interactions that they have been having on campus:

- "It's also been fun to get to meet people in person during the summer." – Teacher 4

One teacher also reflected on feelings they have going into their second summer as their time in the program draws to a close.

- "One benefit about now vs last year in the program is that I know how hectic and stressful the 2nd week is. Because I know about it, I am a little bit prepared to handle it mentally. I am feeling a kind of sadness creeping in that means the program and Chemistry Summer Camp is coming to an end...:(" – Teacher 3

Codebook 4

Codebook 4 then allowed me to break down the teacher statements by source of motivation. Each comment was assessed to determine the focus of the comment, either focused on the participant's learning, their students' learning, or the participant's teaching. Coding frequencies are displayed in Table 181.

Table 181. Summer Journal #2 Coding Frequencies for Summer 1 – CB4

Code	**Abbreviation**	**Total Number of Teachers Represented (*N* = 5)**	**Percentage of Total Responses (%)**
Learning-focused	L-f	5	100
Student-focused	S-f	2	40
Teaching-focused	T-f	5	100

All participants shared comments related to their motivations for their own learning and teaching. Two teachers (40%) gave responses focused on their own students. Some examples of teaching-focused statements are given below.

- "I will be able to bring back a lab that I've wanted to develop but didn't have time before." – Teacher 4

- “It will allow me to discuss some cross-curricular items in my classroom.” – Teacher 1
- “I like the fact that the articles and discussions have been about actual teaching topics related to content, not pedagogy and that we have had labs.” – Teacher 6

All teachers gave statements related to their own learning. Some examples are given below.

- “I feel that I have a much better understanding of the instrumentation.” – Teacher 4
- “Learning a lot about the use of ice cores (in different areas of science.” – Teacher 1
- “I feel that it has given me more of an understanding towards the research process.” – Teacher 5

Two teachers’ comments related to their own students and are given below.

- “I feel that [the summer research experience] gives me more of an appreciation for lab procedures to the classroom and can help me implement a more authentic research experience for my students.” – Teacher 5
- “The led lab was a little frustrating because there didn't seem to be a clear reason why one group got it to work and another group didn't but it's not all bad that we got to experience that same frustration that our kids often do.” – Teacher 4

Summary of Summer Journal #2

The second journal entry described teachers' experience in the SDSU research laboratories and summer courses halfway through their campus experience. The main themes from Summer Journal #2 were:

- All five teachers shared their experience from the first week, each expressing positive gains or reactions. Participants were able to gain confidence and skills after only one week in a research laboratory. Thus, teachers gained KoSc through the research experience, which improved their overall PCK.
- Three of the five teachers discussed interest in bringing the research experience into their classrooms, demonstrating teachers' intention of exposing their students to current scientific research. This highlights participants' KoG, showing improved PCK.
- Two teachers discussed how the laboratory research experience has impacted their view of their own action research, thus influencing other types of research skills. The on-campus summer session allowed participants to grow as scientists, teachers, and researchers.
- Teachers appreciated meeting other MS program participants in person, which strengthened connections made through Zoom and prior course assignments in the online environment. Interactions with other MS program participants supported teachers' development of PCK.

All five teachers shared comments focused on their own learning and teaching, while two teachers were able to relate to their own students' experiences.

Summer Journal #3

The third and final journal entry was prompted after participants had completed their two weeks on the SDSU campus. The prompting questions asked the teachers to reflect on what they have gained through their experience, such as professional development, networking opportunities, and other takeaways. Teachers were also asked to share their thoughts on the summer session, including if their expectations were met, how the on-campus experience went overall, and any other final thoughts on the two-week session.

Codebook 1

Coding frequencies from Codebook 1 are shown in Table 182.

Table 182. Summer Journal #3 Coding Frequencies for Summer 1 – CB1

Code	**Abbreviation**	**Total Number of Teachers Represented (N = 4)**	**Percentage of Total Responses (%)**
Attitudes	A-c	1	25
Skill	S-c	2	50
Teaching	T	3	75
Feedback	F	4	100
Interaction	I	4	100
Goals	G	2	50
Reflection	R	4	100

Reflection

First, three teachers reflected on professional growth they experienced through the on-campus summer session.

- "The summer experience was incredible. Being immersed in chemistry for most of two weeks with a group of people (both fellow grad students and SDSU faculty & researchers) was an environment of rapid growth in understanding how much there is to gain from working with colleagues and not in isolation." – Teacher 2
- "This summer in particularly I have grown over last summer. I believe having the year of reflection, teaching, action research helped along with the focus this summer of lab discussions and then doing the labs in the afternoon have given me direct ideas and practices I will be taking to the classroom." – Teacher 3
- "Lots of reflection really. I sometimes come in thinking I know everything, but I get to talk to teachers and colleagues and get a whole different perspective. The labs we looked and just talking to other about my research helped me in my journey as a researcher and teacher." – Teacher 7

Interaction

The fourth teacher discussed the ability to interact with other teachers on campus and how this influenced their professional development.

- "Being able to collaborate with other science teachers by sharing different tricks of the trade." – Teacher 1

Being on campus also allowed for networking opportunities to arise. All four teachers discussed the interactions that took place that allowed them to deepen existing relationships with other program participants and faculty.

- "Spending the amount of time together that we did made it impossible to not grow those new relationships in a more complete way than just the online Zoom meetings throughout the year had done. Two semesters of Zoom meetings with most of these people made for a great start, a solid foundation. But turning around and being able to jump in with both feet together, where the conversations didn't have a one-hour time limit of sorts was amazing. And those connections continued to grow both casually and formally every waking hour of the summer session on campus." – Teacher 2
- "I am an out of sight out of mind kind of person and so it will be tough for me to maintain connections despite the internet world we live in. I would benefit from some sort of depository that was ongoing for materials and connections. Yes, I know Facebook and similar exist, but I do not do those things and so if there was some sort of similar thing for these chem connections it would be helpful to me. I hope to make connections at ChemEd or similar in the future and one colleague from this summer is in the Twin Cities metro and I hope to connect with him." – Teacher 3
- "Just really getting to know more teachers. Now when I look on Facebook I know who those people are or have a question, I know other resources I can look for." – Teacher 7
- "Tons, other teachers and college professors." – Teacher 1

<u>Reflection</u>

Summer participants were then asked to share what they have taken away from the summer research experience. One teacher reflected on the impact of their experience in the research lab.

- "As a teacher, and perhaps as a scientist too, I found so much benefit in the time working in the lab and seeing how actual bench chemistry looks on a day to day basis. I hadn't done formal bench research in my undergrad years, and realized that I'd missed a big opportunity to see that side of the field…And I really grew in my appreciation for how important this kind of experience can be, even if an undergrad just spent a bit of their time in the lab during those first four years." – Teacher 2

Some of their reflections related to other codes. One teacher reflected on what they have taken away from the summer course that they plan to bring back into their teaching.

- "Bring back [to the classroom] the importance of environmental chemistry and the importance of working together to solve a problem." – Teacher 1
- "The time in the lab showed how important it is to be organized and keep detailed notes on EVERYTHING you're doing, which is something I've always harped on with my own students but now have much more personal experience to reference when making those claims to them…I think students need to understand that the many things we use and take for granted each day each began with a series of 'successes' that brought the inventor, etc., to the final success." – Teacher 2

Another teacher reflected on the interactions that took place on-campus, highlighting the value of the in-person component of the program.

- "Just getting to know people, doing the actual labs, do the actual demos, doing the actual waste class. The online experience is not even close to in person. I feel that more of us interact in person, then on zoom. [Program participant] barely spoke on Zoom, but it was great to get to know him." – Teacher 7

<u>Skills (S-c)</u>

One teacher discussed skills they had gained in the lab and how these skills and knowledge apply to their teaching.

- "Everything...this summer the lab and topic directly applies to the classes I teach and so I will be bringing ice cores to both my chem and Science 9 classes. There are also various cleaning and lab prep practices that I can now bring to my students with a connection to research." – Teacher 3

Another teacher shared how the research experience helped them develop more perseverance.

- "It builds a sense of working through difficulty, and it increases an individual's ability to persevere when things don't go 'your way' or when they aren't 'successful' in the first, second, third, twenty-third attempt. It was amazing to talk to [research professor] and see the volume of data and work he continues to put into his research, the hours that go into one round of testing that may only lead to another set of parameters that didn't work. I really appreciated the classic Edison light bulb quote about how he hadn't failed each time, but that he had been successful in finding many ways that didn't work." – Teacher 2

<u>Goals</u>

Two teachers explicitly expressed that they had met their goals for the summer session, while three discussed whether the on-campus portion of the summer course met their expectations. One teacher also described acting as a mentor to first-year teachers based on their experiences from their previous summer on campus.

- "I went into the summer program hoping to 'suck out all the marrow' from every moment and come home exhausted and excited. The time on campus absolutely met every expectation and exceeded how much value I imagined I could take from the time there." – Teacher 2
- "It did meet my expectations, I got to work with real cells, go through the process of how you deal with cells, but also learn a lot about the lab." – Teacher 7
- "Yes, coming in as a second-year teacher I felt comfortable the entire time and tried to help first-year teachers as much as possible." – Teacher 1

<u>Reflection</u>

To conclude the summer journals, teachers were asked to reflect on their experience on the SDSU campus. One teacher discussed their first summer in the program and described their desire to share the program with interested colleagues.

- "This was my first summer and it was spectacular. I found myself wanting to go home and start spreading the word on this program to young(ish) teachers in my district who might still be looking for a Master's program that is more in their content area and not full of the nonsense that so many programs have for teachers. There were so many instances where I saw the work from the last year of classes find its way back into the conversations and the research time that I was experiencing. There were topics from every content course that I referred to in understanding the research and the article discussions & labs that we worked on in the morning and afternoon sessions for 776, as well as in the 691 class. I don't think anyone could completely script how well the courses play off of each other and reinforce each other, but somehow the plan for this program and the series of courses that go into the experience all build into this really cohesive whole.” – Teacher 2

Three teachers discussed their second – and final – summer experience for the program.

- “This summer was my second and I enjoyed it more than the first. I said on day one that it would go fast and it went even faster than I remembered. It was a boot camp in terms of the constant go go go, but I do not think I would want it any other way...” – Teacher 3
- “I enjoyed 776 more. I thought it benefitted me more going through the labs. I also enjoyed the smaller class size.” – Teacher 1
- “It was a lot better academically. I really enjoyed doing labs in the lab class vs looking at papers. I think this was a cool concept and he should definitely do it again with when we are virtual look at literature, but in person we do a lab. I loved the demos class, that was fun and made me want to either turn the demo into a lab, of just start thinking about more demos as anchoring events. While we did less in the way of bonding as a group, I think it was nice that we were chill. It also had to do with the fact we had one day off this year versus 2.” – Teacher 7

Attitudes (A-c)

To conclude the third journal entry, one teacher shared that they will miss the collaboration and learning that took place through the MS program.

- "I will miss this program. I will not miss the work. I will miss the collaboration, the people, and learning new and exciting things to help my craft as a teacher." – Teacher 7

Codebook 4

Codebook 4 then allowed me to break down the teacher statements by source of motivation. Each comment was assessed to determine the focus of the comment, either focused on the participant's learning, their students' learning, or the participant's teaching. Coding frequencies are displayed in Table 183.

Table 183. Summer Journal #3 Coding Frequencies for Summer 1 – CB4

Code	**Abbreviation**	**Total Number of Teachers Represented (N = 4)**	**Percentage of Total Responses (%)**
Learning-focused	L-f	4	100
Student-focused	S-f	2	50
Teaching-focused	T-f	4	100

All four teachers gave statements motivated by their learning and teaching. Two teachers described student-focused motivations related to program takeaways. Some examples of teaching-focused statements are given below.

- “Lab discussions and then doing the labs in the afternoon have given me direct ideas and practices I will be taking to the classroom.” – Teacher 3
- “I will miss the collaboration, the people, and learning new and exciting things to help my craft as a teacher.” – Teacher 7

Teachers also gave statements related to what they learned during the on-campus experience. A selection of responses is given below.

- “I got to work with real cells, go through the process of how you deal with cells, but also learn a lot about the lab.” – Teacher 7
- “There were so many instances where I saw the work from the last year of classes find its way back into the conversations and the research time that I was experiencing.” – Teacher 2

Two teachers discussed program takeaways they plan to bring back to their students. These examples are listed below.

- “The time in the lab showed how important it is to be organized and keep detailed notes on EVERYTHING you're doing, which is something I've always harped on with my own students but now have much more personal experience to reference when making those claims to them.” – Teacher 2
- “There are also various cleaning and lab prep practices that I can now bring to my students with a connection to research.” – Teacher 3

Summary of Summer Journal #3

The third journal entry was completed after the conclusion of the in-person component of the summer courses. Four teachers submitted journal entries, with all sharing feedback about the experience, interactions that took place on campus, and an overall reflection on their experience. The experience allowed teachers to reflect on takeaways motivated by their own learning and teaching. The main themes from Summer Journal #3 were:

- Through the research experience, teachers observed how chemistry research is conducted on a day-to-day basis, which would allow them to bring back practical knowledge and skills to their own students. The on-campus component of the MS program could have direct impacts on student learning in the lab and emphasized increased KoG and KoSc, demonstrating increased PCK.
- Participants discussed the impact of interactions with other teachers, stating that these connections influenced their professional development and allowed them to strengthen existing relationships with their peers. These interactions also allowed for teachers' development of PCK.
- Teachers described the challenges of the intensity of the two-week session but expressed contentment with their overall experiences.

Post-Campus Summer Survey

After the conclusion of the two-week on-campus session, participants were invited to complete a survey about their time on campus. Teachers discussed the most and least beneficial aspects of the two-week experience, how their view of the research process has or has not been impacted by their time in SDSU research labs, and if they plan to change the laboratory work they do with their students as a result of their experience in CHEM 776. Teachers also provided feedback for the summer courses, which was sent directly to MS program instructors.

Codebook 1

Coding frequencies for Codebook 1 are presented in Table 184.

Table 184. Post-Campus Summer Survey Coding Frequencies for Summer 1 – CB1

Code	**Abbreviation**	**Total Number of Teachers Represented ($N = 3$)**	**Percentage of Total Responses (%)**
Attitudes	A-p	3	100
	A-c	3	100
Knowledge	K-p	3	100
Teaching	T	3	100
Feedback	F	3	100
Interaction	I	2	66.7
Experience	E	3	100
Reflection	R	2	66.7

<u>Teaching and Reflection</u>

All three participants first shared what aspects of the two-week experience that they found to be most beneficial. The first participant discussed the impact the course activities had on their future teaching.

- “The articles/activities that we began and ended the day with each held a lot of worth on their own and will almost certainly make their way into my plans for my classes this year. Those discussions and the chance to try the activities ourselves right there - immediately - were so valuable, as we so often go to professional conferences where we hear about an activity or lab but don't get to ‘play with it’ ourselves then and there, only to return home and lose the interest since we didn't invest ourselves in it. Those articles and activities were great, and they brought about a TON of side conversations among the group where we could share related activities, ideas, perspectives that went beyond the article itself. They were a great way to bookend the day, loosening up our brains and then putting a nice, tidy bow on the day by circling back to it.” – Teacher 2

Three teachers discussed the benefit of participating in laboratory research, with one teacher sharing how they plan to share this experience with their own students.

- “The work we were able to take part in while in the individual labs was incredibly meaningful in forming my perspective and ability to share the value of bench research with my future students.” – Teacher 2

- “Being in the research laboratory. This is probably the only time I am going to be able to work with ice cores in my lifetime so that was pretty neat.” – Teacher 1
- “Time in the Ice Core lab.” – Teacher 3

<u>Interaction</u>

Participants also shared the value of being able to interact with fellow science teachers.

- “Discussing items with other science teachers is incredibly beneficial to see what works in their classroom that could work in my classroom.” – Teacher 1
- “Camaraderie with fellow teachers…Teachers work in isolation much of the time and so to have time to debrief and share when the pressures of the job have been lifted is a great experience that is unrivaled in any other setting I have had beyond this program.” – Teacher 3

Least beneficial aspects were all coded as feedback and were shared with MS program instructors.

<u>Attitudes (A-c) and Knowledge (K-c)</u>

The survey also asked teachers to reflect on their attitudes toward the research process prior to coming to campus and how their thoughts and understanding have been impacted by their time in the SDSU research labs. Below are examples from each of the three teachers. Both Teachers 1 and 2 discuss their observations of research faculty and teaching assistants creating new tools and devices to solve research questions.

- Teacher 1:
    - Prior: “Data collection to answer a problem.”

    - Current: “I was surprised by how much the scientist in our department had to engineer different tools to solve problems they encountered.”
- Teacher 2:
    - Prior: “I think I would have had a description that was rather dry and tedious. I would have described the work as very serious and not at all humorous or spontaneous. I probably would have pictured it as routine and monotonous, an endless loop through the textbook scientific method that I have taught for years.”
    - Current: “The experience really showed me how creative the process can be. It is a serious business, but it is not at all monotonous or dry. The work I took part in with [research professor] was constantly evolving, and the inventiveness that was necessary to blaze trails that don't already exist was visible every day. [research professor] was trying something new all the time, and came with new ideas every morning. It's clearly something that he has immense passion for, which made me remember how many of my waking (and not so waking) hours are taken up in trying to get better at my craft. His work is immensely creative, and he is literally inventing new devices that are needed for his work to progress that don't already exist ‘for sale’ conveniently. He is a steward of resources who makes the most of every dollar entrusted to him; this was another reminder of how similar education looks at the K-12 and post-secondary levels.”

- Teacher 3:
    - Prior: "I worked in labs as an undergraduate and worked in [research program for teachers] for one summer so I have experience with this and it matched for the most part."
    - Current: "Loved the ice cores, but the experience itself is how I remembered. It is slow and plodding, but that is because we are doing things humans have never done before and we want to get it right..."

<u>Teaching</u>

After participating in research on campus and testing labs in CHEM 776, teachers were asked to describe if they would change their approach to laboratory work with their students because of their experiences in the course. Participant responses are given below.

- "I will definitely continue to use labs that are largely unscripted and open-ended. I have a habit of giving students a blank sheet of paper or Google Doc that is their lab assignment, with the rather wry instruction that they have to create it all from scratch. After the brief experience of working with [research professor], I realized that there is great value in experiencing the sensation of 'building the plane as we fly it' in terms of collecting all of the information and organizing it, drawing conclusions, making the next plans, and report on your progress - all while not being given a script or guidebook to lead me through the abyss!" – Teacher 2

- "For sure, the Ice Core lab we developed will be used AND there are at least 2 labs we discovered in the daily discussions that I will be using. Keep up this exposure." – Teacher 3
- "I will take back ideas from our class discussions, the labs we tried, and ideas from our research laboratory work to discuss with students." – Teacher 1

Codebook 4

Codebook 4 then allowed me to break down the teacher statements by source of motivation. Each comment was assessed to determine the focus of the comment, either focused on the participant's learning, their students' learning, or the participant's teaching. Coding frequencies are displayed in Table 185.

Table 185. Post-Campus Summer Survey Coding Frequencies for Summer 1 – CB4

Code	**Abbreviation**	**Total Number of Teachers Represented ($N = 3$)**	**Percentage of Total Responses (%)**
Learning-focused	L-f	2	66.7
Student-focused	S-f	2	66.7
Teaching-focused	T-f	3	100

Two teachers shared statements motivated by their students' learning and their own learning, while all three teachers described teaching-focused motivations. Some examples of statements focused on teaching are given below.

- "Discussing items with other science teachers is incredibly beneficial to see what works in their classroom that could work in my classroom." – Teacher 1
- "The articles/activities that we began and ended the day with each held a lot of worth on their own and will almost certainly make their way into my plans for my classes this year." – Teacher 2

Two of the three teachers shared statements related to their own learning that occurred during the two-week campus experience. Some examples are given below.

- "The chance for the 1st year people to sit in and see the presentations from the 2nd year students about their now-completed research was VERY valuable." – Teacher 2
- "This is probably the only time I am going to be able to work with ice cores in my lifetime so that was pretty neat." – Teacher 1

Two teachers also described how their experience would impact their future students. A selection of responses is given below.

- "I will take back ideas from our class discussions, the labs we tried, and ideas from our research laboratory work to discuss with students." – Teacher 1
- "The work we were able to take part in while in the individual labs was incredibly meaningful in forming my perspective and ability to share the value of bench research with my future students." – Teacher 2

Summary of Post-Campus Summer Survey

Teachers were invited to complete a summer survey, which collected feedback on the summer research experience. Three participants completed the survey. The main themes from the post-campus summer survey were:

- Being in a research laboratory would allow teachers to share experiences and new knowledge with their students, highlighting improved PCK quality through the intertwining of multiple knowledge bases.
- Participants expressed surprise with the creative nature of the research process, possibly hearkening back to the creativity focus of the CHEM 778 course. This observation would allow teachers to introduce creativity into their instruction in new ways, particularly through lab activities. This indicated improvements to their KoCO, KoT, and KoR as components of their overall PCK.
- Participants reflected on how they would change how they approach labs in their classrooms, whether by bringing in new labs from the CHEM 776 discussions or information gained from their research lab experience. This demonstrates the summer experience's impact on teachers' view of how they incorporate laboratory techniques and applications into their instruction. The experience allowed teachers to improve their KoSc and KoT, thus improving their overall PCK.
- Teachers again emphasized the value of interacting with and learning from other science teachers in the program. These interactions supported participants' PCK and professional development.

All three teachers expressed teaching-focused motivations when reflecting on the campus experience. Additionally, two of the three teachers shared statements motivated by their own learning, as well as their students' learning.

End-of-Summer Survey

The end-of-summer survey follows the same format as the other end-of-semester surveys and focuses on what knowledge and skills teachers gained from these courses, along with feedback that participants have shared. The end-of-summer survey was analyzed using Codebooks 1 and 4.

Codebook 1

Coding frequencies for Codebook 1 are given in Table 186.

Table 186. End-of-Summer Survey Coding Frequencies for Summer 1 – CB1

Code	**Abbreviation**	**Total Number of Teachers Represented (*N* = 4)**	**Percentage of Total Responses (%)**
Attitudes	A-c	1	25
Knowledge	K-c	4	100
Skill	S-c	2	50
Teaching	T	4	100
Feedback	F	4	100
Interaction	I	4	100
Reflection	R	4	100

Teaching and Reflection

When discussing meaningful aspects from the summer courses, many teacher statements were coded as feedback; however, two of the teachers explained how the summer experience allowed them to reflect on what they learned in CHEM 776 and how this new knowledge applies to their teaching.

- "So for me as a learner and as a teacher, I have come to realize how important reflection is. This is why the reviews on the activities and online discussions were very meaningful. That being said the summaries of the articles were not as meaningful and I think that has to do with the fact that did not get to see it in motion. So when looking at the hands on activities and labs I was able to do them physically. That means I could reflect on how they worked and how I could apply this to my classes." – Teacher 7
- "The aspects that were most meaningful were activities that helped me either create something new for my classroom or learn about new ideas that I would like to use in my classroom with my students. I really enjoyed the face to face time when we discussed an article in the morning and then actually tried it out in the afternoon." – Teacher 17

Teachers then reflected on how the courses benefitted them. In addition to the laboratory development course, participants also explained how the demonstrations, waste disposal, and action research courses impacted them.

- "The courses each hit on something needed and something good. I am glad I took the two independent study courses as they hit on topics I needed." - Teacher 6

- “788 helped me finish my paper and create my defense. I enjoyed listening to other students’ projects. I thought it was beneficial to get peer review. 776 I love coming to SDSU and getting to participate in the labs and with fellow students.”– Teacher 1
- “I enjoyed being in a research lab, seeing how science is actually done, and thinking about how to connect my experience to my students in my classroom.” - Teacher 17
- “I want to be a more hands-on teacher, being good with chemicals and using demonstrations. I feel that the more hands-on you are as a teacher the better your students will learn. That being said I also want be able to connect with students to the real-life applications of science.” - Teacher 7

Similarly, the participants discussed each course’s value for money. In comparison to the rest of the program courses, on-campus credits are more expensive for out-of-state students than online credits.

- “Well I had to pay out of state tuition because it was listed as an on-campus class to that skews my thoughts.” – Teacher 6

The other three teachers reflected on aspects of the courses that influenced their thoughts on whether the cost of the courses was “worth it.”

- “776- again to me this is a vital course 788-helps you finish your paper.” – Teacher 1
- “I came away with many new ideas for my classroom and learned about things that I would not have learned otherwise. I was able to collaborate with peers and

learn from experts/mentors. I was able to finish my degree and be proud of the work that I did to complete my research project." – Teacher 17

- "For the most part they are worth the money. The real-life experience of doing demos and research is not something that you can do any day, and very few programs, if any offer them. Other programs are only composed of classes that do not reflect what is needed to grow myself in class. IN this case both 776 and 691 does. The reason 777 is the same ranking but for a different reason. As stated before I am lost when it comes to research. It is not my strong suit and honestly why I chose not to pursue chemistry as a major. But this type of research was exciting and the support that was needed/ given in the class was crucial to me finishing this program." – Teacher 7

In terms of expectations for the summer session, all four participants stated that there wasn't anything that did not meet their expectations. The following comments describe aspects of the summer experience that exceeded their expectations.

- "I learned more about ice core research in 2 weeks than I thought possible." – Teacher 17
- "I really thought doing the labs we read about in 776 was very beneficial." – Teacher 1
- "The value of in person collaboration on the papers for 776, the collaboration about projects for 777." – Teacher 6

Knowledge (K-c)

The participants were then asked to discuss how their chemistry content knowledge had changed due to summer program requirements.

- “Better lab knowledge through 776.” – Teacher 1
- “I gained knowledge in how to do demos, disposal, and also in organic chem.” – Teacher 6
- “I learned quite a lot about analytical chemistry and analytical techniques.” – Teacher 17
- “I think it is not the chemistry content in the sense that I know about thermodynamics, but that I am more comfortable with labs and have a better knowledge of how certain demos work, the science behind those demos, and how to clean them up.” – Teacher 7

Teaching

In terms of pedagogy, each of the teachers discussed how they would apply their new knowledge and skills in the classroom.

- “I have some different ideas about how I want to approach labs in my classroom, and how demos should be carried out and students held accountable.” – Teacher 6
- “More abilities to explain different topics through hands-on labs.” – Teacher 1
- “The discussions and activities we did at the start and end of the day helped me to think about different ways to approach certain topics and new things to try in my classroom.” – Teacher 17
- “Between performing the labs that us students made up, writing the reviews of how I will do demos in my class, and trying out the labs given through the ACS I have seen how different ways we can conduct lessons and labs.” – Teacher 7

Attitudes (A-c)

One teacher also discussed feelings of excitement for trying new labs that were discovered through the CHEM 776 discussions.

- "I am really excited to try to implement these different labs." – Teacher 7

Interaction

When reflecting on additional gains because of the MS program this summer, teachers described the benefits of interacting with other teachers on campus, as well as faculty and GTAs.

- "Connections and relationships" – Teacher 6
- "It's very beneficial to communicate with the other teachers, professors, and grad students about what is going on in science." – Teacher 1
- "Friendships, a network of highly capable and passionate peers, and learning about other cultures from the graduate students and faculty." – Teacher 17
- "I think making connections. I am so happy to have meet such wonderful chemistry teachers. I hope our connections and friendships do not fade over time." – Teacher 7

Teaching and Reflection

The program participants were asked to explain how they have become more effective teachers after participating in summer courses. Three of the teachers discussed new resources that they plan to bring into their future teaching.

- "I have a large assortment of demos and activities to implement to keep my class engaging and fresh. I also have been exposed to many different thoughts and beliefs about classrooms and teaching strategies that have expanded my thinking about my own classroom." - Teacher 6

- "I am thinking more intentionally about how to present material to my students to make it more engaging and how to make challenging concepts more understandable (Ex: energy levels and electrons)." – Teacher 17
- "I can take back to my classroom new ideas from fellow teachers." – Teacher 1

The fourth teacher revealed some hesitation regarding their teaching effectiveness.

- "I do not know if I have [become a more effective teacher]. I just hope that the lesson, and support network I have gained this summer makes me a better teacher. But I cannot say for sure." – Teacher 7

Codebook 4

Codebook 4 then allowed me to break down the teacher statements by source of motivation. Each comment was assessed to determine the focus of the comment, either focused on the participant's learning, their students' learning, or the participant's teaching. Coding frequencies are displayed in Table 187.

Table 187. End-of-Summer Survey Coding Frequencies for Summer 1 – CB4

Code	**Abbreviation**	**Total Number of Teachers Represented (*N* = 4)**	**Percentage of Total Responses (%)**
Learning-focused	L-f	4	100

Student-focused	S-f	3	75
Teaching-focused	T-f	4	100

All participants shared statements that were motivated by their own teaching and learning. Three of the four participants described student-focused motivations. Some examples of teaching-focused statements are given below.

- "I can take back to my classroom new ideas from fellow teachers." – Teacher 1
- "I have a large assortment of demos and activities to implement to keep my class engaging and fresh. I also have been exposed to many different thoughts and beliefs about classrooms and teaching strategies that have expanded my thinking about my own classroom." – Teacher 6

All four teachers also shared statements focused on their own learning. A selection of responses is given below.

- "I learned quite a lot about analytical chemistry and analytical techniques." – Teacher 17
- "I am more comfortable with labs and have a better knowledge of how certain demos work, the science behind those demos, and how to clean them up." – Teacher 7

Three teachers also discussed motivations related to their own students. Some examples of participant responses are given below.

- "I am thinking more intentionally about how to present material to my students to make it more engaging and how to make challenging concepts more understandable." – Teacher 17
- "I feel that the more hands on you are as a teacher the better your students will learn." – Teacher 7

<u>Summary of End-of-Summer Survey</u>

The end-of-summer survey allowed teachers to provide feedback on summer courses, which was sent directly to MS program instructors. In addition to feedback, teachers also discussed knowledge and skills that were gained through the two-week summer session. All four teachers shared new knowledge, how the experience related to their teaching, and the impact of in-person interactions. The main themes from the end-of-summer survey were:

- All teachers reflected on their summer experience, stating that the most meaningful aspects of the summer courses related to what they could apply to their own teaching, including bringing real-world experiences into their classrooms related to laboratory research and demonstrations. This demonstrates increased KoSc, KoG, and KoT, thus revealing an increase in teachers' PCK quality.
- All teachers discussed knowledge that they gained through their work in the research labs, as well as learning more about new lab activities, waste disposal, and chemical demonstrations. This new knowledge identifies new resources (KoR) and teaching strategies (KoT) that the teachers can bring back to their classrooms, also highlighting increased PCK.

- All four teachers also expressed making connections with other program participants, again highlighting the meaningful nature of interacting with other science teachers. These connections supported teachers' PCK and professional development.
- The summer research experience improved participants' teaching effectiveness by improving several components of their PCK and allowing them to reflect on how they approach teaching labs in their classrooms. However, although they stated they felt like they became a better teacher through the experience, one teacher expressed uncertainty that any positive changes in their teaching effectiveness took place. This indicates potential improvements to their KoT as a component of their overall PCK.

All participants possessed teaching-focused motivations, with three teachers also sharing their thoughts on how their experience will impact their own students.

GTA Survey

Graduate teaching assistants (GTAs) from the Department of Chemistry & Biochemistry worked with the MS program participants in the research labs. To understand how the two-week experience went from a mentoring perspective, a post-survey was given to GTAs following their work with the teachers. Four GTAs responded to the survey. Three of the GTAs were returners who had worked with the MS teachers in the past; one GTA was working with the teachers for the first time. Because the survey was anonymous, Table 188 displays frequencies of each code's appearance in the dataset, not how many GTAs were represented by the code.

Table 188. GTA Survey Coding Frequencies for Summer 1 – CB1

Code	**Abbreviation**	**Frequency (N = 33)**	**Percentage of Total Responses (%)**
Attitudes	A-c	5	14.7
Skill	S-c	8	23.5
Goals	G	4	11.8
Feedback	F	3	8.8
Interaction	I	1	2.9
Reflection	R	12	36.4

Each of the GTAs discussed how they felt working with the teachers from the MS program. All four shared positive comments about working with and interacting with the MS participants. Data coded as feedback was sent directly to MS program instructors.

Reflection

Two returners discussed what they have learned working with the teachers.

- "It was really nice to work with them. They came to know me well. It was certainly a teacher and student relationship, but it became a friendship, also. They were not afraid to incorporate the friendship into our work together. I think that has influenced a great deal the way I work with students." – GTA 4 (Returner)
- "Working with the teachers was a good experience as it has been in previous years. I find that I don't get a lot of my own research during this time, as I'm

preparing for the next day's worth of work with the teacher plans, but I enjoy the time and learning from them." – GTA 2 (Returner)

The other two GTAs discussed talking about research with the teachers.

- "It was nice to talk about research with high school teacher." – GTA 3 (Returner)
- "It was pleasing and refreshing showcasing my project." – GTA 1 (1^{st} year)

Goals

The GTAs discussed their goals for this experience and whether they believed these goals were met. Three of the four explicitly stated that their goals were met.

- "My goals were to help them understand our research and how this research outcome help in understanding the about the past climate and whole earth global ecosystem. I believe most of my goals were able to [be] met." – GTA 4 (Returner)
- "My goal is always to have them learn something new, and to bring ideas back with them to teach their own students. I believe these were accomplished." – GTA 2 (Returner)
- "For them to be able to perform and understand what we did in our labs. Yes, the goals were met." – GTA 1 (1^{st} year)
- "To make sure science spread [sic] everywhere." – GTA 3 (Returner)

All four GTAs reflected that the experience working with the MS teachers was what they had expected.

Skill (S-c)

When asked what they thought the MS participants learned through the experience, each shared various skills that they intended for the teachers to develop over the course of the two-week experience.

- "I had planned for the teachers to learn new techniques each day of their time with us, and considering the questions they had asked during their I believe they accomplished some of those goals. My plan was to bring something they could use to take back with them." – GTA 2 (Returner)
- "The teachers learned the teamwork, dedication and hard work is required to get the goal. I mean research goal." - GTA 4 (Returner)
- "They learnt how to perform cytotoxicity assays such as MTT and also cell matrix adhesion assay." – GTA 1 (1st year)
- "I think they have learned how to do active research." - GTA 3 (Returner)

Reflection and Skill (S-c)

In addition to teaching the MS participants, the GTAs were asked if they learned anything from this experience. Two teachers shared that they have learned from the teachers who participate in the program.

- "I have learned that regardless of the number of times I do this exercise I still learn new things from teachers that come in every year… I also get a chance of knowing the teaching methodology, like conducting interesting laboratory experiments, creating fun facts about science etc." - GTA 2 (Returner)
- "I also learned some important aspect of teaching science in high school, which is very challenging." – GTA 4 (Returner)

One teacher discussed learning what the teachers were capable of doing in the research lab.

- “The ability the teachers had to perform aseptic technique.” – GTA 1 (1^{st} year)

Another teacher mentioned the skills that they were able to develop through this teaching and mentoring experience.

- “Collaborative work and leadership skill… It's [gave] me better thinking ability [sic].” – GTA 3 (Returner)

Reflection and Attitudes (A-c)

The returning GTAs were asked to compare the Summer 2022 experience with previous summers. One teacher shared being more excited to work with the teachers, while another discussed that the experience seemed to be on par with past summers.

- “This summer was my second time working with high school teachers. So, I was more excited to help them.” - GTA 4 (Returner)
- “Apart from the COVID year online, this year was much the same as previous years.” – GTA 2 (Returner)

All four GTAs stated that they would like to work with the teachers again in the future and explained why.

- “Of course, I am always excited to work with teachers in future. As, I was a high school teacher in the past and I also love teaching So, always like to work with them.” – GTA 4 (Returner)
- “I would work with teachers again in the future if the chance arose, they always provide a good time with good insight.” – GTA 2 (Returner)
- “I want to. It's made communication better.” – GTA 3 (Returner)

- “Because we had fun.” – GTA 1 (1st year)

To conclude, the survey invited any additional thoughts the GTAs had about their participation in mentoring the MS teachers. One GTA summarized the two-week experience with the following statement:

- “It's fun and a good experience laying down what we did in our lab but in the simplest form.” – GTA 1 (1st year)

<u>Summary of GTA Survey</u>

Four GTAs completed a post-survey about their experience working with MS teachers in their research labs. Comments from the GTAs involved goals for the teachers, attitudes and skills that the GTAs gained through their experience, and a reflection on their time working with the MS participants. The main themes for the GTA experience were:

- The GTAs demonstrated the symbiotic nature of involving graduate students in the MS campus experience. Through mentoring the MS teachers, GTAs were able to gain leadership skills and pedagogical knowledge, while supporting the participants’ professional development through the gain of research and laboratory skills.
- All four GTAs expressed interested in working with the teachers again in the future, with all indicating positive attitudes toward the experience.

<u>Summary of Summer 1</u>

During the first summer session, methods included the ASCI (pre/post), three summer journal entries, a post-campus summer survey, and the end-of-summer survey.

Teachers experienced professional development through their two-week session on the SDSU campus. The main themes for Summer 1 were:

- Teachers did not experience statistically significant changes in their attitudes toward chemistry laboratory research after participating in an SDSU research lab; however, they did express positive attitude changes related to their laboratory skills and confidence, which potentially improved their future laboratory teaching approach. By combining their improved KoSc with their KoT, teachers demonstrated improved PCK quality.
- Although teachers expressed mixed emotions toward coming to campus, the two-week experience allowed participants to bring back practical knowledge and skills to their own students. Participants also hoped to bring real-world experiences into their classrooms related to laboratory research and demonstrations. Thus, the on-campus component of the MS program could have direct impacts on student learning in the lab and emphasized increased KoG, KoT, and KoSc, demonstrating increased PCK quality.
- Teachers planned to bring new laboratory approaches and resources into their teaching, demonstrating a direct impact of the MS program on its participants' instruction. CHEM 776 discussions and experiences led to teachers' development of KoR, KoSc, and KoCO, which demonstrated improvements to their overall PCK. The summer research experience improved participants' teaching effectiveness by improving several components of their PCK and allowing them to reflect on how they approach teaching labs in their classrooms.

- Teachers emphasized the value of forming or strengthening relationships with each other, GTAs, and SDSU faculty while on campus. Teachers learned from each other and developed KoR and KoT that led to improvement of their overall PCK. Interactions between MS program participants allowed for professional development and increased PCK.
- Participants described challenges with the intensity of the two-week session but expressed positive attitudes toward the summer campus experience overall.
- Teachers gained knowledge in the CHEM 776 course, as well as the waste disposal and demonstrations elective courses, that enabled them to gain KoR and KoT that would positively impact their future teaching and increase their overall PCK. The summer courses allowed participants to grow as scientists, teachers, and researchers.
- Relating back to the CHEM 778 course, teachers observed creativity in the research labs, which would enable them to incorporate creativity into their own laboratory instruction. This development of KoT, in combination with their KoSc, indicated improved PCK quality.

Semester 3

During Semester 3, teachers were able to participate in two content courses. CHEM 774 focused on electrochemistry, kinetics, and nuclear chemistry topics. CHEM 775 focused on organic and biochemistry topics. These courses were fully online and primarily asynchronous. Optional weekly Zoom sessions were offered for each course and were the only synchronous components. The data for Semester 3 is presented chronologically. A pre-content survey was sent out at the start of Semester 3. The CoRe and Teaching Script assignments were both due near the end of the semester, along with module surveys. The End-of-Semester survey was sent out after the conclusion of the semester. Table 189 discusses the methods used during the Semester 3.

Table 189. Semester 3 Data Collection Methods

Term	**Data Collection Methods**	**ID Codes**
Semester 3	**CHEM 774:**	
	Teaching Script	TS
	Module Survey	MS
	CHEM 775:	
	CoRe	CoRe
	Module Survey	MS
	General:	
	Chemistry Content Survey (pre-test)	CCS
	End-of-Semester Survey	EOS

Chemistry Content Survey (pre-test)

The pre-content survey was used to establish a baseline for participants' chemistry content knowledge. Only one participant completed both the pre- and post-surveys, so the data will be shown for a single participant: Teacher 9. The full chemistry content survey can be found in Appendix P. The survey consisted of three past AP Chemistry free-response questions related to the three content courses offered in the 2022-2023 academic year.[2] The content survey was scored using AP Exam scoring guidelines.[2] Scores for each question, course connections, comfort level rating, and confidence level rating data are shown in Table 190. The comfort level related to their comfort with the content of the question. The confidence level related to the participant's confidence with the accuracy of their answer.

Table 190. Pre-Chemistry Content Survey Score and Analysis for Teacher 9

Question	Course Connection	Point Total	Comfort Level (1-6)	Confidence (1-6)
1	CHEM 773	2/6	1	1
2	CHEM 774	0/3	1	1
3	CHEM 775	3/3	2	1

The overall score for Teacher 9's pre-content survey was 5/12. They related low comfort levels with the content and low confidence in the accuracy of their responses. Specific errors in calculations and explanations will be discussed when comparing changes between the pre- and post-content exams later in the chapter.

CoRe

In Fall 2022, the CoRe was administered in CHEM 775: Organic & Biochemistry. The CoRe was analyzed using Codebook 2 to assess participants' PCK. Table 191 displays the codes from Codebook 2 that appeared in the Semester 3 CoRe.

Table 191. CoRe Coding Frequencies for Semester 3 – CB2

Code	Abbreviation	Total Number of Teachers Represented (*N* = 16)	Percentage of Total Responses (%)
Knowledge of science	KoSc	16	100
Knowledge of goals	KoG	16	100
Knowledge of students	KoSt	16	100
Knowledge of curriculum organization	KoCO	16	100
Knowledge of teaching	KoT	16	100
Knowledge of assessment	KoA	16	100
Knowledge of resources	KoR	15	93.8

Examples of KoSc

The first component of PCK represented in the CoRe is KoSc, which includes science content, scientific practice, the nature of science, and scientific progress.[41] Participants identified a challenging topic related to organic and biochemistry topics. The most commonly chosen topics were nomenclature (*N* = 6), functional groups and organic reactions (*N* = 6), intermolecular forces and their impact on properties (*N* = 3), and energy metabolism ($N = 2$). Most participants chose topics related to organic chemistry rather than biochemistry. Teachers described their reasoning behind their topic choices, including challenges to their own understanding or experience level.

- "My unfamiliarity in the topic would be my primary concern." – Teacher 38
- "This topic is challenging because it's one that doesn't make as much sense to me and I find it hard to communicate well about things which I can't understand as well." – Teacher 36
- "Amino acids and protein structure would be most difficult for me to teach. It has been a very long time since I took biochemistry, and I don't teach this from year to year." – Teacher 22

Some challenges arose from the content itself, especially for those choosing to teach organic nomenclature.

- "This topic can be challenging to wrap your head around because of the multiple ways to name molecules. Organic molecules can be named using common names and IUPAC names." – Teacher 11
- "I believe this would be difficult to teach as it is important to understand multiple components of the process and how the components interact." – Teacher 37
- "I chose this topic because there are so many rules involved with naming organic compounds. Naming organic compounds is almost like learning a new language. It takes a lot of practice and, at some points, memorization, to learn IUPAC nomenclature. I think this would be difficult to teach because of all the rules and different possible substituents." – Teacher 20

- "Not only are there several different intermolecular forces at work in both inorganic and organic chemistry, those forces are responsible for explaining many different properties." – Teacher 30
- "I also think this topic can be hard to picture for myself and my students." – Teacher 37

Participants then discussed their intentions for student learning, including learning outcomes for their CoRe lesson. A selection of responses is given below.

- "Students should learn how to define what esterification is, the esterification process, and how it looks within an acid or a base." – Teacher 39
- "What I hope the students get out of this topic is a basic understanding of nomenclature of organic molecules." – Teacher 11
- "I want them to learn Lewis dot diagrams so that they can check for bond polarity and VSEPR geometry. This way they can differentiate London Dispersion (LDF) from dipole-dipole or Hydrogen bonding since LDF are generally the only intermolecular forces found in nonpolar molecules." – Teacher 43

After sharing intended learning outcomes, teachers explained what additional knowledge they have on their topic beyond what they would teach to students. Some examples of participant responses are given below.

- "One major aspect of these newly added functional groups that I do not intend to include in the class content would be anything to do with nomenclature." – Teacher 2
- "Due to metabolism's complexity there is sufficient material that will not be covered in a high school nutrition or food science class. Some of the details will

be left out to simplify the lessons. An example would be the details of the beta oxidation of fatty acids." – Teacher 37

- "I know that amino acids have an amino group on the N terminal end and a carboxylic acid on the C terminal end, and they have different side chains that contribute to their properties." – Teacher 22

The final component of the CoRe targeted at teachers' KoSc focuses on the difficulties or limitations associated with teaching the content. Some teacher statements related to the content itself.

- "Cellular respiration is a very complicated process. It occurs at the microscopic level, so many students have trouble visualizing an abstract process." – Teacher 40
- "This is a very specific topic that occurs in several steps so a challenge would be boiling it down to the overarching step and not over-simplifying it." – Teacher 36
- "The main difficulty with teaching metabolism is the complexity of this topic." – Teacher 37

Relating to the content, multiple teachers identified the difficulties associated with naming organic molecules.

- "Where to start counting for the attachments is always a difficult part of nomenclature. I even know you count for the smallest number and I still find myself defaulting to counting from the left to right at first. Another difficult part is making sure everything is in alphabetical order. Sometimes, I included, you get wrapped up in solving the problem and forget to go back and double check your work." – Teacher 14

- "Finding and numbering the parent chain is not always left to right [and] understanding where substituent or functional group should go based on numbering." – Teacher 25
- "I think it also can be difficult for students because you can name or draw something completely right, except start from the wrong carbon and it isn't actually right, or their structures could look different but still be the same thing. That is where I have struggled is thinking I am doing and learning correctly but then finding out I just started on the wrong side or had a branch set up wrong." – Teacher 6

One teacher discussed the need to build foundational knowledge with their students prior to introducing their chosen topic.

- "The major difficulty with teaching this lesson is that students will need some background knowledge in regard to: what organic molecules are, basic organic molecular drawing, functional groups, and some nomenclature. Therefore, this would require some time prior to getting to the lesson on the classification of major organic reactions." – Teacher 13

One teacher described both their KoSt and KoR while discussing difficulties associated with teaching their selected topic.

- "The spatial abilities to 'see' polarity based on shape are difficult for students. Modeling kits and modeling programs always make a great tool, but the inability see atoms and molecules always makes teaching to teenagers a difficult ask. They like visible proof and boiling water is a difficult 'proof' of water polarity."

Summary of KoSc

In the CoRe, participants were able to explain their topic choice, intentions for student learning, and difficulties or limitations associated with their topic. The main themes for KoSc were:

- Teachers anticipated difficulty teaching organic and biochemistry topics due to a lack of experience, low confidence in their content understanding, and the complexity of the topics themselves. Teachers were able to identify how they would bypass these obstacles by addressing how they plan to bring these topics into their classroom in a manageable way.
- Participants are aware that different naming conventions exist for organic molecules, which could pose issues when introducing nomenclature to students. This demonstrates that teachers understand which aspects of the content may be most challenging for their students, demonstrating both KoSc and KoSt.
- Teachers were able to differentiate between the content they would bring into their instruction and the content knowledge they possess beyond what they would teach students, demonstrating scientific content knowledge that was developed in CHEM 775.

Participants expressed limitations to their own organic and biochemistry content knowledge but could describe how they would bring these topics into their classrooms despite these challenges.

Examples of KoG

The next code for the CoRe assignment relates to KoG, which may include learning goals for scientific literacy, real-life application, and integrated understanding.[41] Participants revealed their KoG by describing the importance of learning their chosen concept. Many teachers described how the content itself was important to learn in order to provide the foundational knowledge necessary to understand other scientific concepts.

- "Amides are critical in the function of proteins and enzymes. The linkage made between two amino acids – called a peptide bond – are made with amides." – Teacher 38
- "It is important for students to see how reactants react with a catalyst to form products. It is also important to understand how the conditions such as acid or basic solution can affect the product outcome." – Teacher 39
- "It is important for students to understand cellular respiration and energy metabolism because these are foundational concepts to understand many aspects of biology and biochemistry. Energy flow is an important concept in ecology and evolution." – Teacher 40

In addition, teachers described the importance of forming connections between chemistry concepts.

- "Understanding the basic structure for an organic compound is important for students to make connections between polarity, solubility, and how they interact with other compounds." – Teacher 25
- "It is important for students to know how to name compounds because the name describes the structure of the compound. Then, the structure determines the properties and reactivity of the substance. By knowing the name of a substance, students can infer how that substance behaves and reacts with other materials." – Teacher 20

- "Students…need to be able to connect heat of vaporization/condensation and heat of fusion/solidification to boiling point and freezing point temperatures so they can make an accurate explanation for phase changes asked in either format." – Teacher 43
- "Students in chemistry often see physical properties as 'just the way things are,' rather than having a chemical reason behind them. When we see the interactions between molecules of a substance or interactions between a solute and solvent, we can further appreciate the explanatory power of the science and the amazing order and structure of the world." – Teacher 30

Teachers also stated that their chosen topic would allow students to develop skills necessary for chemistry.

- "For students to discern when and where within a molecule a reaction will occur is a fundamental chemistry skill. Students need to build on the oxidation-reduction idea as they are introduced to more complicated, multi-step reactions to better predict final products." – Teacher 36
- Nomenclature "also challenges students problem solving and reasoning skills. The lesson does this by asking students to determine which rules to use, double check their work to make sure they did not miss a step and determine the type of chemical they are trying to name." – Teacher 14

Several teachers mentioned that their chosen topic would prepare students for further science education.

- "Given the time constraints of high school and having to teach to the standards, I believe learning the basics of naming would benefit students who are going to need organic chemistry in their post-secondary education… I remember feeling overwhelmed when I took my first organic chemistry class, and I just want to help to alleviate some of the anxiety and fear of taking on organic chemistry." – Teacher 11

- "I think covering the basics of naming and drawing alkanes, alkenes, and alkynes would be enough to give students a peek into organic but not totally overwhelm them. It'll give them the foundation to understand the basics and maybe that'll help them later when they do take an organic chemistry class." – Teacher 25
- "I want students to be prepared not just for a first-year college chemistry course, but the beyond – hopefully helping prevent a 'cliff' in organic chemistry." – Teacher 27
- "Also, students taking advanced science courses in high school are more likely to take science coursed in college and will be better prepared after learning some basic biochemistry." – Teacher 22
- "This is the basics of all organic and biochemistry. Lots of students at our school are interested in these topics and they have very few opportunities to be exposed to this type of chemistry before college." – Teacher 6

In a similar vein, learning organic chemistry topics could help prepare students for their future careers.

- "It is important for students to learn basic organic chemical reactions because it focuses on carbon-based life forms. All reactions, therefore, will relate to life. Several careers apply the use of these reactions including medical doctors, veterinarians, dentists, pharmacologists, chemical engineers, and more." – Teacher 13

- "Career exploration: students research careers related to nutrition, exercise, or cellular respiration. Students find education requirements, salary, and job duties for careers such as nursing or personal trainer." – Teacher 40
- "A factor that influences me to want to teach this is how relevant it is in life and in future careers. This would drive me to strive to teach this topic to my students." – Teacher 13

Two teachers discussed the importance of preparing students for AP tests.

- "Traditionally, the Unit 3 content in the AP curriculum is recognized as the unit that comprises the largest portion of the exam questions. Any new/additional emphasis placed on this unit's content that also serves to deepen student comprehension of the standards within Unit 3 can have wide reaching impact on student success." – Teacher 2
- "Because these are standards in the AP Biology course description, they will be tested on the AP Biology exam." – Teacher 22

Finally, participants described the importance of introducing students to organic and biochemistry topics that connect to their students' everyday lives.

- "Energy flow… is also important to understand nutrition." – Teacher 40
- "Metabolism is an important topic for Food Science and Nutrition. Metabolism explains how your body turns food into energy and sustains life… There are many metabolic diseases that require an understanding of metabolism to understand how the disease works. Examples of metabolic diseases include diabetes, heart

disease, maple syrup urine disease and many others covered in a nutrition course." – Teacher 37

- "It is important for students to know nomenclature because of the application to real life. Students are encountering chemicals in their daily lives. Having the knowledge of how chemicals are named could help students identify the chemicals in the products or food they are buying." – Teacher 14
- "A great way of gauging student understanding would be to have students present one major important organic chemical reaction and the impact it has on our daily lives." – Teacher 13

Summary of KoG

Upon discussing the importance of teaching their chosen topic, teachers demonstrated their KoG, particularly relating to helping students develop the skills and knowledge necessary to prepare them for future work and education. The most common themes for KoG were:

- Teachers have a desire to prepare students for the future, whether it be for future chemistry studies, career paths, or everyday life.
- Teachers are aware of the interconnectedness of chemistry concepts and feel a responsibility to provide their students with foundational knowledge and skills that will help them form stronger connections between topics. This demonstrates teachers' PCK by rationalizing the purpose of presenting students with specific chemistry content.

- Teachers can make connections between the curriculum and assessment by stating the need to prepare students for standardized testing, showing another aspect of teachers' PCK.

The participants were able to make connections between their chemistry content knowledge and goals for student learning, demonstrating PCK and revealing the nature of their teaching motivations.

Examples of KoSt

The next code is KoSt, which may focus on different learning levels, needs, interests, prior knowledge, ability, learning difficulties, and misconceptions.[41] First, teachers identified the class to which they would teach their chosen topic. Many teachers chose to teach their concept in an advanced chemistry or biology course, such as Honors, AP, or a dual credit college level course ($N = 12$). Two teachers chose to teach organic and biochemistry topics in a lower level general chemistry course. One teacher chose to teach a biochemistry concept to their nutrition and food science courses.

Touching on their KoSt, participants found it difficult to teach their chosen topic due to challenges students face when learning these topics.

- "Students aren't too familiar with organic chemistry, so having them apply those concepts to biological systems would be difficult for them." – Teacher 22
- "Students would have a different set of rules to remember for naming. I have also found nomenclature is hard for students regardless of what they are naming." – Teacher 14
- "Different types and IUPAC naming of isomers is something that students can see in the moment and learn for a test but are frequently confused later when the topic

continues to reappear… If students have a surface level understanding, they can make it through a unit test, but are at a deficit for the rest of the course as they must continually figure out what is meant by each type of isomer." – Teacher 27

- "I think the concept most challenging to teach would be the intermolecular forces. There are so many different types (I like to focus on the dipole-dipole, H-bond and London Dispersion/Van Der Waals) trying to get the students to focus on the three major forces without including the others." – Teacher 43

Several teachers highlighted their KoSt by describing common student misconceptions or errors.

- "Common mistakes by students are that they may assign an amide as basic because of the presence of the N atom. Nitrogen is only basic when they are part of a functional group (such as an amine) or in the molecule guanidine which can bond to some amino acids." – Teacher 38
- "Another problem is the misconceptions associated with this topic. One common misconception is that food becomes energy that can be used by the body to exert in activity. A good portion of this energy actually goes toward maintaining homeostasis in the body. Another misconception is that only carbohydrates fuel the body. Lipids and proteins also play a role in providing fuel." – Teacher 37
- "As I mentioned above, students have a lot of pre-existing notions about the similarities between elements that are in the same group on the periodic table, in this case oxygen and sulfur in particular. My choice of sulfur based functional groups for this new topic exploration is sure to do battle with their 'muscle memory' from those earlier courses." – Teacher 2

- "Students will probably struggle with the organic functional groups and knowing how they will react. They may also have difficulties deciding how the interactions between amino acids influence the protein structure." – Teacher 22
- "Some difficulties I can foresee with this information would be having students understand the priority functional groups. They would have to know how to number the carbons based on the substituent groups present." – Teacher 20
- "I also see the difficulties students may have with understanding and even imagining some of the less permanent forces." – Teacher 30

The next component of the CoRe asked teachers to share their knowledge about students' thinking based on experiences and interactions they have had with students in the classroom.

Some teachers remarked on their students' learning preferences.

- "I would first think about how my students learn best. Upon figuring that out, I would incorporate the different learning styles into my teaching material." – Teacher 11
- "Students in these classes like hands-on activities and opportunities for discussion." – Teacher 37
- "Students like to have step-by-step instructions when learning something. I would present this information ins a step-by-step manner for them…This way of teaching helps students organize their thoughts and helps prevent them from missing steps." – Teacher 20

Teachers also discussed their students' prior knowledge that would prepare them to learn organic and biochemistry topics.

- "Students will have knowledge of functional groups and that these groups determine how a molecule will behave chemically. Biologically speaking, they would have basic idea of what proteins and amino acids are and what purposes these molecules have in a human body." – Teacher 38
- "Students have a background in chemistry and biology to understand this topic. In these classes, chemistry and biology are reviewed so they should have the basic understanding of macromolecules and energy cycles." – Teacher 37
- "Students would have a basic level of chemistry – having all taken at least a year of high school chemistry. Students would be familiar with VSEPR, Lewis structures, and basics of IUPAC naming system." – Teacher 27
- "Students have been exposed to geometric shapes and to the concept of bilateral symmetry. They have even been exposed to radial symmetry. I try and draw upon these lessons from math to get them to understand dipole moments of polar shapes." – Teacher 43

Similarly, teachers addressed students' lack of prior knowledge and how this gap would inform their instruction. Participants also referenced topics or skills that their students have struggled with in the past.

- "Students will be newly exposed to organic molecules and common reactions. They will not have much in the way of their thinking that would cause confusion." – Teacher 13
- "Students in biology may have limited chemistry experience. They will have difficulty interpreting diagrams that use chemical symbols." – Teacher 40

- "I have experienced some of my students do okay in linear, straightforward thought, but struggle when concepts come back around and create a more complicated situation…Students at this age also are still working on abstract thought, so pictures or models and seeing real examples is important for understanding and retention." – Teacher 30
- "What gives students issues would be keeping track of things, many of them don't slow down enough or care enough to make sure they don't make mistakes." – Teacher 6

Some teachers reflected on students' experience with specific chemistry topics, sharing predictions for student interactions with their chosen topic and goals for future learning.

- "One rather specific area that I think will benefit from this new idea is how students sometimes become over-attentive to the possibility of hydrogen bonding in a given compound, especially organic molecules that are presented as part of practice problems." – Teacher 2
- "Students sometimes get muddled up when it comes to redox/electron transfer. I think that they could memorize it, with some success, but this is about more than memorizing, it's about why does this particular reaction happen and not any other reaction at that particular place in the molecule." – Teacher 36
- "Knowing that students struggle with organic and functional groups, I would need to review functional groups and intermolecular forces prior to this lesson. I plan to use many different visuals to help with the amino acid structures, formation of peptide bonds, and protein folding. I think this would help them get a better understanding of the concepts." – Teacher 22

Finally, one teacher discussed their students' attitudes toward learning science and how this challenges their teaching.

- "I currently teach freshman physical science, the biggest obstacle I see in my students thinking is they will convince themselves they're not good at science and put up their own learning block. Even with positive reinforcement and repetition some students are unable to overcome their own self-doubt." – Teacher 39

When discussing factors that influence their teaching, teachers discussed their students' prior knowledge and how this would influence their instruction. This combines their KoSt and KoT, which demonstrates improvements to teachers' overall PCK.

- "One important factor is the students' prior knowledge from their middle school science classes. There will be varying levels of knowledge based on what the middle school teacher chose to emphasize. Many students have a much better understanding of photosynthesis than cellular respiration." – Teacher 40
- "Students have heard of H-bonding in biology before they come to me. They have some misconceptions because their biology teachers have told them covalent bonding is stronger than ionic bonding. I have to let them know that this is only true in aqueous systems, like the human body. The opposite is true in the nonpolar air on the desktop. It is something to consider when you start talking about these things." – Teacher 43
- "These students in AP should have good understanding of how to draw Lewis structures and covalent bonds for basic molecules." – Teacher 6

Summary of KoSt

Teachers shared their KoSt by anticipating student reactions to organic and biochemistry topics, particularly in relation to their prior knowledge (or lack thereof). Participants also discussed their students' preferred learning methods and how this would inform instruction of their chosen topic. The main themes related to KoSt were:

- That teachers are aware of how their students might struggle as they introduce topics related to organic or biochemistry, demonstrating a combination of PCK components.
- Most teachers would choose to introduce organic and biochemistry topics to advanced chemistry or biology students, which reveals teachers' knowledge of students' abilities and how these topics would align with existing curricula.
- Teachers understand students' level of prior knowledge, as well as their learning preferences, showing how teachers incorporate their students' needs into their instructional choices.

Participants' KoSt demonstrates a higher level of PCK by demonstrating their ability to anticipate student behavior and plan instruction according to students' learning needs. Teachers also expressed KoSc, KoCO, KoG, and KoT in conjunction with their discussion of their KoSt. For the semester 3 CoRe, the components of PCK are becoming more intertwined in participant responses.

Examples of KoCO

The next code describes KoCO, which may relate to state and local standards.[41] In the CoRe assignment, teachers are asked to name the standards that are relevant to their chosen topic. Most teachers used NGSS standards (N = 11), while some used guidelines from the AP Chemistry or Biology framework ($N = 4$). One teacher used state-specific standards. One teacher stated that none of their state standards align with organic chemistry concepts, so they "I would save this topic until the end of the year, and do it as just an introduction to the basics so students are able to see it before taking organic chemistry classes in college." This statement also aligns with this teacher's KoSt and KoG.

In terms of making decisions about what to teach, many teachers identified time constraints as one of the biggest limitations associated with teaching organic and biochemistry topics in their classrooms.

- "Naming takes a lot of practice and there just isn't enough time for students to become proficient in it unless I am willing to sacrifice my standards to teach them. So, I am looking to give them an introduction into the basics of nomenclature, and depending on the time, it may vary in the depth it is introduced." – Teacher 11
- "The greatest limitation would be limited time to introduce organic chemistry to students in a high school chemistry or AP chemistry classroom. With that limited time things such as nomenclature and basic structures could be introduced, more complicated concepts would have to wait." – Teacher 39
- "Time. Currently, this is not a part of our Chemistry or Differentiated Chemistry, or AP Chemistry objectives. So, if used in AP Chemistry, this will be an introduction and that it all." – Teacher 27
- "I think time is also a limitation here. There is a ton of information to go through in AP chemistry, so I would have to determine how much time I want to spend on

naming organic compounds. I may not be able to go as in depth as I would like." – Teacher 20

- "The most limiting factor for all teachers applies here: time. When I look at all of the topics able to be discussed in general high school chemistry, I see so many that are steppingstones to the next topic. While I appreciate the explanatory power of intermolecular forces, I can easily see them as a topic that I can "skip" in order to make more time for the more core concepts." – Teacher 30
- "Time. This is a lengthy unit and our current AP teacher doesn't cover it." – Teacher 6

<u>Summary of KoCO</u>

Teachers were generally aware of standards that could guide their teaching of organic and biochemistry concepts. In addition to standards, teachers discussed time as a limitation to their ability to make decisions about what topics to introduce in their classrooms. The main themes for KoCO were:

- Time constraints were a prevalent concern for teachers, many of whom felt that they would not have much time in the school year, if any, to bring new topics into their curricula.
- Teachers were able to determine which standards related most closely to their chosen topic, which would allow them to bring organic and biochemistry topics into their high school science classrooms.

<u>Examples of KoT</u>

The next code is KoT, which involves the discussion of teaching methods and activities.[41] First, teachers were asked to share the teaching procedures related to their chosen topic. Most teachers included multiple teaching strategies in their response to this prompting question. Many teachers ($N = 11$) chose to use group work through practice problems or project-based learning. Labs/demonstrations ($N = 8$) and direct instruction ($N = 10$) were also commonly chosen instructional methods. Several teachers decided to use modeling when teaching organic and biochemistry topics ($N = 6$). Others included discussion ($N = 5$) or reading/writing ($N = 1$) in their lesson plan. Three teachers explicitly described using scaffolding when introducing organic chemistry topics to their students.

Then participants were asked to share the factors that influence their teaching. A few teachers discussed how their own lack of prior knowledge would impact their teaching.

- "I am by no means an expert on nomenclature so in order for me to be successful I must prepare. If I am unprepared for the lesson, the students would pick up on that right away. Which in turn, would make it difficult to draw them back into the topic." – Teacher 11
- "The amount of resource material can influence me as well. I do not consider myself to be strong when we get to these types of biological models, so I would probably rely on my resource materials such as textbook, worksheets, online supplemental materials, and labs to help me fill in the gaps that the students may have throughout the lesson." – Teacher 38

Many teachers mentioned student accommodations or how the specific group of students they have in their classroom would influence how they teach.

- “Depending on the students I have, it would limit the amount and depth of knowledge I would be able to go within this topic.” – Teacher 11
- “This topic would need to be revisited and used throughout the year in order for students to truly catch on. In the AP setting, the goal would be to expose students to the idea, so they are set up to better understanding whenever they take further classes.” – Teacher 27
- “One of the biggest factors with this is that there will be students who may be slower learners or students that have a student plan – such as an IEP or 504.” – Teacher 38
- “Other factors that would influence me teaching this idea would include being able to collect proper support materials for my students to augment their learning of the idea. Creating a comfortable learning environment were students feel at ease asking questions in front of their classmates.” – Teacher 39
- “Pulling students into the intrigue and applicability of these forces should help create interest and solidify thinking.” – Teacher 30

Some participants mentioned their inability to cover topics in depth or how time constraints impact how much organic and biochemistry material they decide to cover in their classrooms.

- “It would mean sacrificing other topics in chemistry, though. Because of this, the depth to which we cover these reactions would not be deep in order to make as much room for other basic and standard chapters in chemistry at the high school level.” – Teacher 13

- “Scheduling is always a factor in schools. I would do my best to make sure the lecture, work time on problems, quiz and lab would all be within the same week. That way students do not get a break in the instruction. When that happens, students forget main ideas and get confused on the topic.” – Teacher 14
- “I would take into consideration the length of the class periods, how many students are in the room, and the number of days I have to teach the material. There is a fine line between covering enough content in a class period and covering too much.” – Teacher 20

Some teachers discussed using the CoRe itself as a method to figure out how to best prepare a lesson for teaching their chosen topic.

- “I am currently teaching naming of ionic compounds to my chemistry students and they are really struggling. I find myself consistently responding to questions from students with that just the way it is. I hope that by working on this CoRe assignment for organic naming and structure I can find some better methods to help.” – Teacher 6
- “One other area that led me to choose this for my focus on this assignment is in simply experiencing a sort of fatigue in trying to write new, effective, and varied practice and assessment items on these topics.” – Teacher 2

Summary of KoT

All teachers were able to outline which teaching procedures they plan to use in their instruction of organic and biochemistry concepts. The main themes for KoT were:

- That all teachers used multiple methods of instruction to effectively teach higher level organic and biochemistry concepts to their students, which combines their content knowledge and pedagogical knowledge, thus demonstrating higher quality PCK.

- Prior knowledge with respect to both teachers and their students impacted how participants teach organic and biochemistry topics to their high school students. The level of prior knowledge influenced the amount of time spent discussing foundational concepts and the depth to which teachers were able to cover their chosen concept.
- Again highlighting multiple components of PCK, teachers shared how they would adjust their instruction based on the specific students involved in the learning process. Participants were able to anticipate differences in student learning as they created a CoRe.
- Teachers used the CoRe assignment itself to reflect on how to best teach their chosen topic to their students.

Participants revealed their teaching approaches for bringing organic and biochemistry topics into their high school science classrooms. As with prior semesters, teachers included multiple teaching methods and approaches in a single lesson and were able to reflect on how to adapt their instruction to best suit their current students' learning styles.

Examples of KoA

The next code is KoA, which details teachers' knowledge of formal and informal assessments and feedback.[41] Several teachers discussed assessment methods in the teaching procedures section of the CoRe.

- "The misconceptions could be managed with a pre-test and discussion opportunities. Questions can be posed through the think pair share and modeling to help students break misconceptions." – Teacher 37
- "Also, I use discussion to get students talking about the topic and their ideas, questions they have, and misconceptions they may have about the topic. After the lesson is finished the students would complete a homework assignment, and I would try to find another lab to help cement the students understanding of the topic. We would go over the assignments and lab so that we could address any incorrect answers and/or misconceptions." – Teacher 11
- "I would also work to augment my current collection of practice and assessment items (that up to this point focus on oxygen functional groups) to incorporate the new options added with this work and deepen their overall understanding and assessment quality." – Teacher 2
- "Activate and assess students' prior knowledge with a pre-assessment." – Teacher 40
- "The bell work would have a problem from the quiz on it. After bell work, students would take the quiz. They would be able to use their notes on the quiz." – Teacher 14

Teachers then discussed how they would assess student understanding or confusion. Like with the teaching procedures, most participants chose to utilize multiple assessment methods. The assessment methods identified in the Fall 2022 CoRe were checking for understanding through practice problems ($N = 13$), listening to student discussions ($N =$

9), direct questioning ($N = 5$), formative or summative tests/quizzes ($N = 4$), and presentations ($N = 3$).

Many teachers discussed their role during formative assessments, as well as the purpose of chosen assessment methods. Teachers primarily discussed the importance of identifying student misconceptions and observing student work to determine how to adjust subsequent instruction. Some examples of teacher statements are given below.

- "Students may relay information without understanding so it will be important to listen for misconceptions. Additionally, students may be at different levels. Pairs can be adjusted so that students who need extra help can receive help from students who are showing stronger levels of understanding." – Teacher 37
- "Here, I can determine misconceptions that the students have toward the topic…I can also use this to pull out students to get them the extra assistance that they may need to get to become successful." – Teacher 38
- "Listen to students in pairs for any misconceptions or confusion in their definitions of redox." – Teacher 36
- "The data from the formative assessments would show me areas that need to be retaught, clarified, let me know my students have a firm understanding, and are ready for more information." – Teacher 39
- "This allows for students to help each other and allows me to see where students would be making mistakes. It also gives me the chance to encourage students while they are working to help build their confidence." – Teacher 14

Summary of KoA

By discussing specific ways of ascertaining student understanding or confusion, participants shared assessment methods for their chosen topics. The most common themes for KoA were:

- All teachers identified multiple formative and summative assessment methods to use during their instruction or organic and biochemistry topics.
- Teachers provided rationale for their assessment choices and described in depth how and why they would assess students, showing a deeper KoA than in previous semesters. This demonstrates more developed PCK over time.
- Participants described the importance of formative assessment in identifying student misconceptions, thus focusing on the purpose and utility of assessing student understanding throughout instruction.

Through their Fall 2022 CoRe, teachers demonstrated higher quality KoA, which in turn indicated high quality PCK.

Examples of KoR

The final code in Codebook 2 relates to KoR, which discusses materials and activities that teachers utilize in their classrooms.[41] Participants demonstrated their KoR by identifying which resources they would use in their teaching of organic and biochemistry topics. In the teaching procedures section of the CoRe, teachers expressed knowledge of POGIL and other group activities ($N = 8$), lab activities and demonstrations ($N = 5$), computer modeling software or molecular modeling kits ($N = 5$), videos ($N = 1$), and readings ($N = 1$) that could be used during instruction.

When discussing limitations associated with teaching their chosen topic, one teacher expressed difficulty due to a current lack of resources. However, this teacher expressed their ability to overcome this obstacle.

- "A limitation could be an effective lab for naming of alcohols. I have not done one before so that would take some research and possibly buying of supplies." – Teacher 14

Summary of KoR

Throughout the CoRe, teachers discussed materials and activities that they planned to use for instruction of their chosen topic. Some teachers attached files of worksheets for labs/activities or links to readings/videos, however, most described their teaching procedures without indicating any specific resources. One teacher described the need to seek out resources in order to effectively teach their lesson.

Summary of CoRe Data

In Semester 3, teachers completed a CoRe in the CHEM 775 course, which focused on organic and biochemistry content. Many teachers felt that their content knowledge in these areas was limited, but still expressed a strong grasp of the challenging content they chose for the CoRe assignment. Participants brought organic or biochemistry topics into their high school science classrooms with their students' learning styles and prior knowledge in mind. Most teachers possessed all seven components of PCK, with most also demonstrating higher quality PCK than in previous semesters. The main themes that appeared in the CoRe were:

- For organic and biochemistry topics, which are not typically included in the high school chemistry curriculum, teachers expressed concern that they would not be able to introduce these topics due to a lack of time; however, teachers also identified the importance and value of bringing these concepts into their classrooms. Teachers felt that touching on these topics would provide students with necessary foundational knowledge that would adequately prepare them for future studies or experiences. By combining their KoSc, KoG, and KoSt, teachers demonstrated improved PCK quality.

- Participants demonstrated a strong content understanding of their chosen topic (KoSc) and a well-developed plan for how they would incorporate this topic into their teaching (KoCO and KoT), which revealed increased PCK for organic and biochemistry concepts.
- Teachers differentiated instruction for diverse groups of students in their classrooms and were able to go into more depth in regard to assessment methods. By demonstrating increased KoSt, KoT, and KoA, teachers displayed improvements to their overall PCK.

For the Fall 2022 semester, participants demonstrated a combination of knowledge bases in each of their responses to the CoRe prompting questions while also expressing their reasoning behind their teaching choices, thus revealing higher quality PCK.

Module Survey – CoRe

After completing the CoRe assignment, teachers were invited to complete a survey about their experience creating a CoRe for their topic. Fourteen teachers completed the CoRe module survey in Fall 2022. In the survey, participants were asked if they would feel comfortable teaching their chosen topic without preparation. Of the 14 teachers, 8 (57.1%) would not feel comfortable, 2 (14.3%) would feel comfortable, and 4 (28.6%) would feel comfortable teaching without preparing beforehand but did not think it was a good teaching practice to do so. When asked about their confidence level on a scale of 1 to 6 for teaching their concept, the average confidence score was 4.00. Upon creating a CoRe for their topic, 2 teachers (14.3%) did not find it challenging and 12 (85.7%) did find it challenging, with 3 of these teachers finding only some aspects to be challenging. The CoRe module survey was coded using Codebooks 1 and 4.

Codebook 1

Coding frequencies for the Semester 3 CoRe module survey can be found in Table 192.

Table 192. Module Survey Coding Frequencies for Semester 3 CoRe – CB1

Code	**Abbreviation**	**Total Number of Teachers Represented (*N* = 14)**	**Percentage of Total Responses (%)**
Attitudes	A-p	2	14.3
	A-c	12	85.7
Knowledge	K-p	2	14.3
	K-c	8	57.1
Skill	S-c	2	14.3
Background	B	4	28.6
Teaching	T	13	92.9

Feedback	F	4	28.6
Modules	M	7	50
Interaction	I	2	14.3
Reflection	R	12	85.7

Examples of Attitudes (A-p and A-c)

Two teachers discussed attitudes they held prior to the course, with both expressing concerns with learning or teaching organic and biochemistry concepts.

- “At the outset of this course, I had concern over the applicability of the content of biochemistry and organic chemistry on my day-to-day teaching.” – Teacher 30
- “Not only is this content something I would not have felt at all comfortable with before this course, it certainly would not have made its way into my work with the CoRe assignment.” – Teacher 2

In terms of current attitudes, most teachers (78.6%) shared their feelings after participating in the CHEM 775 course, including comfort level and confidence with the content. One teacher described increased confidence in their content knowledge after taking the course.

- “The opportunity to work in organic chemistry topics has enhanced my own content confidence in ways that I never anticipated due to my undergraduate experiences in organic chemistry being rather poor.” – Teacher 2

Multiple teachers discussed their attitudes toward learning CHEM 775 concepts, particularly related to the difficulty of the material.

- “I felt that learning the content for myself was difficult.” – Teacher 39

- "It was difficult at first but once I got going on it I realized that I had put in the hours this semester to learn this topic better than before." – Teacher 6
- "I am not very good at most organic chemistry concepts." – Teacher 11
- Creating a CoRe "was kind of challenging because this is a topic that I am not super comfortable with." – Teacher 20

Some teachers described positive attitudes, including increased confidence, toward bringing their CoRe ideas and topics into their classrooms.

- "I feel more confident in my understanding so can therefore summarize the material better for the students." – Teacher 37
- "I felt more confident with writing the CoRe and teaching the lessons." – Teacher 25
- "I am looking forward to implementing my ideas from the CoRe assignment." – Teacher 11

One teacher described their excitement and motivation for applying new knowledge and ideas to their curriculum, even to the extent of bringing a new chemistry course into their school.

- "I enjoyed the process and expect to be using it as a springboard for creating better assignments in this vein…So many exciting things!...Our school did not offer the Advanced Chemistry class that another school in our district has, but now I feel qualified to bring that class here and as one more opportunity for students to be excited about chemistry and see connections." – Teacher 27

One participant discussed a lack of interest in bioorganic topics, which influenced how challenging they found the CoRe assignment.

- "Bioorganic topics, to me, involve more biology really. I don't have much of an interest in it. I know there is quite the connection between Chem and Bio, and perhaps my interest would be stronger the more I learn." – Teacher 38

When discussing what would increase their confidence teaching their chosen topic, two teachers expressed wanting more experience or practice, while one teacher wanted to discuss their pedagogy with colleagues.

<u>Summary of Attitudes (A-p and A-c)</u>

Several teachers described their attitudes while explaining their experience completing a CoRe for their chosen organic or biochemistry topic. The most common themes for prior and current attitudes were:

- Completing a CoRe for a challenging topic allowed some teachers to become more confident in their content understanding; however, some participants revealed that a lower interest or comfort level with the topic impacted the difficulty of the assignment.
- Learning organic and biochemistry topics was challenging for teachers but prepared them to bring these topics into their classrooms.
- Increased understanding or practice creating a lesson by way of the CoRe allowed participants to apply organic and biochemistry topics to their teaching, which led to improved teaching confidence for many.

<u>Examples of Knowledge (K-p and K-c)</u>

When discussing the knowledge they gained in CHEM 775, two teachers shared how their chemistry knowledge has been transformed through the course.

- "This course has helped me understand organic naming and drawing more, and especially since I'm taking the course this semester, it's made some things I have forgotten throughout the years come back to the surface." – Teacher 25
- "Again, I think the ability to make organic and biochemical connections to content will really pique students' interest and improve retention overall. Previously, I would have just stuck to water when teaching intermolecular forces." – Teacher 30

One teacher discussed their level of prior knowledge of organic chemistry in comparison to other topics touched on in other MS program courses.

- "I am not anywhere near as familiar with some of the organic content as I have been with earlier material in other courses and even in the first part of this course." – Teacher 2

Four teachers (28.6%) expressed that gaining more organic and biochemistry knowledge would increase their teaching confidence of their chosen topic.

Several participants discussed how the course content impacted their level of content knowledge related to organic and biochemistry. Some examples are given below.

- "This course has given me more in-depth knowledge of energy metabolism…This class has helped to refresh [undergraduate] knowledge." – Teacher 40
- "The content of this course has greatly increased my chemistry knowledge…As I think about how I struggled with certain concepts, it makes me think about how I learn…what is traditionally 'tougher.'" – Teacher 36
- "The content of this class has given me a better understanding of organic and biochemistry." – Teacher 20

- "The content helped me to review organic and biochemistry concepts that aren't in the current curriculum and to make connections between chemistry and biology. I was also able to use some organic functional group concepts in with some of the biochemistry topics we learned this semester." – Teacher 22

Two teachers discussed knowledge of applications and strategies they would utilize when teaching their chosen concept.

- "I feel I have a plethora of examples to use" when teaching intermolecular forces. – Teacher 30
- "I know have a list of strategies I could implement that would tie to this topic." – Teacher 6

Summary of Knowledge (K-p and K-c)

Over half of CHEM 775 participants (57.1%) shared their current level of knowledge after participating in the course. The most common themes related to knowledge were:

- The CHEM 775 course exposed teachers to new organic and biochemistry topics, as well as refreshed teachers' prior knowledge.
- Teachers expressed feeling better equipped to teach organic and biochemistry concepts after taking the course due to increased KoSc and KoR, which demonstrates increased PCK.
- Further increasing teachers' content knowledge of these topics would increase their teaching confidence.

Skill (S-c)

Two teachers discussed skills they developed through the CHEM 775 course.

- "This module has forced me to think ahead and plan in greater detail." – Teacher 40
- The CoRe module "has made me a stronger teacher and more aware of where my students might struggle." – Teacher 37

One teacher gained skills planning lessons in greater detail, while the other was able to think from their students' perspective. Both teachers touched on their KoT and discussed how the MS program course helped them further develop their pedagogical skill.

Background (B)

Four teachers discussed the influence of their background, including education and teaching experience, on their attitudes toward and knowledge of organic and biochemistry.

- "I have never taught this concept before in class. As a matter of fact, I haven't had this content or even thought about it for close to 30 years. I remember the college course in which this information was presented, but after not using it for nearly 3 decades, all but basic memories remain." – Teacher 38
- "I knew [energy metabolism] in detail during my undergraduate work, but I had forgotten many of the details in the ensuing years." – Teacher 40
- "I had great biochemistry instruction as an undergrad but even that seemed somewhat undercut by my substandard organic chemistry instruction." – Teacher 2
- "Isomers were not taught in our chemistry courses." – Teacher 27

Most teachers expressed a gap in their knowledge or teaching experience due to a lack of recent instruction or practice with a given topic. These participants shared details of their background that led them to explain how the CHEM 775 course had impacted their content knowledge due to these prior gaps.

Examples of Teaching (T)

All teachers but one (*N* = 13) remarked on their teaching in relation to their experience creating a CoRe for a CHEM 775 topic. Multiple teachers shared that they do not currently teach this topic or have never taught this topic in previous courses either.

- “I have never taught this topic in a class before and am really getting more familiar with it myself.” – Teacher 27
- “I don't teach this concept in any of my classes.” – Teacher 22
- “I have never actually been able to teach this topic before.” – Teacher 11
- “I haven't really planned out a lesson about IUPAC naming before.” – Teacher 20
- “Time will tell, if I am ever able to teach [my chosen topic] or not.” – Teacher 6

Teachers also discussed how creating a CoRe allowed them to reflect on how they would teach this topic.

- “The topic that I chose for my CoRe was some new ground for me so developing ways to incorporate it into my course content definitely forced me to understand the material better in the first place but also reflect on how two best utilize that information in a class that has a rather strict curriculum and a tight timeline.” – Teacher 2
- Creating a CoRe “was challenging in a good way that required me to reevaluate the way I teach this topic. I was able to spend time reviewing a topic I teach often.” – Teacher 37

- “I actually decided to add in some organic naming and drawing with my classes this year. [The CoRe] made me consider what I would focus on or skip next year for better student comprehension.” – Teacher 25
- “Since I have not taught an upper level chemistry it was a little difficult to think about how to scaffold for them.” – Teacher 6

One teacher shared how understanding and anticipating student confusion would allow them to improve their instruction.

- “Understand[ing] where students will get confused…could help improve my approach to teaching this concept.” – Teacher 20

Nine teachers (64.3%) felt that more teaching experience would allow them to feel more confident teaching their chosen concept, demonstrating their desire to apply new content and pedagogical knowledge.

Several teachers explained how the CHEM 775 course content impacted their CoRe. Many participants mentioned bringing new content and pedagogical strategies into their teaching.

- “I have put more into the teaching of my organic functional groups than just learning them and learning how to name them.” – Teacher 43
- “The content of this course has…challenged me to incorporate more organic chemistry concepts or ideas into my teaching.” – Teacher 36
- “I would not have been able to teach this concept without this course. I had to work in this course to understand but I was able to use some of the strategies I prepared for myself to learn for my students.” – Teacher 6
- “I have revamped the quality of what I teach.” – Teacher 37

- “I was also able to use some organic functional group concepts in with some of the biochemistry topics we learned this semester.” – Teacher 22
- “The content has impacted my CoRe assignment because I was able to think about and prepare for teaching a topic I have never been able to teach before…I definitely want to include more organic chemistry into my teaching in the future.” – Teacher 11

Teachers also discussed how their experience creating a CoRe and working with challenging topics informed how they would teach in the future. The CHEM 775 course prepared participants to apply new knowledge, skills, and activities to their teaching.

- “As I think about how I struggled with certain concepts, it makes me think about…how I can better teach what is traditionally ‘tougher.’” – Teacher 36
- “I think [the course content] helps my own teaching because I can connect topics together better and I have a deeper understanding of the way molecules interact.” – Teacher 20
- “I feel that the course gave me a basic frame for the information, and now it’s up to me to fill that frame with a method that students can understand that will lead to a high-level learning for all, including myself.” – Teacher 38
- “The specific topics of my CoRe are not things that I would have taught in the past at all but the way that they will fold into my instruction regarding intermolecular forces and the relevant topics in the AP chemistry curriculum will be very positive for years to come. I anticipate that my students will have a much deeper and broader understanding of certain aspects of the intermolecular forces

content because of the additions that will come about via the CoRe assignment." – Teacher 2

- "Going forward, I definitely want to include more activities like the hyperdoc and the aspirin (or wintergreen) lab." – Teacher 25

Summary of Teaching (T)

Upon reflecting on their creation of a CoRe for their chosen topic, most participants ($N = 13$) discussed the CHEM 775 course's impact on their instruction. The main themes related to teaching were:

- Although many teachers had never taught their chosen topic before, the CHEM 775 course allowed them to gain the knowledge and skills necessary to prepare a lesson on an organic or biochemistry topic.
- The CHEM 775 course inspired teachers to bring more organic and biochemistry concepts into their current teaching.
- Many participants discussed their KoT in conjunction with their KoSc and students, thus demonstrating PCK.

Feedback (F)

Data coded as feedback was sent directly to MS program instructors.

Examples of Modules (M)

When reflecting on their experience creating a CoRe, some teachers commented on the assignment itself or their process for creating a CoRe.

- "This assignment requires more detailed planning than a simple lesson plan." – Teacher 40

- "Creating the Content Representation was an easy and straightforward process." – Teacher 39
- "Writing the CoRe as I taught was very easy." – Teacher 25

Teachers also shared feedback on the CoRe module, which was sent directly to MS program instructors.

Some participants shared how the CoRe assignment allowed them to think about how they would like to bring their chosen topic, or related organic and biochemistry concepts, into their classroom. For some teachers, the CoRe was their first opportunity to consider how they would teach organic or biochemistry at the high school level.

- "I have never actually been able to teach this topic before, so creating a CoRe has given me a great place to start!" – Teacher 11
- "This module gave me a chance to sit down and work through the challenges of teaching this concept." – Teacher 20
- "This module allowed me to choose a topic that could fit into an advanced high school chemistry course and connect multiple science fields." – Teacher 22
- "I would say that the assignment challenged me to think more deeply about the subject and my students in a way that was helpful and more complete than I would have done on my own… While I do not teach these subjects specifically, this CoRe assignment is just one example of content in the course that I am able to use as examples in my own curriculum." – Teacher 30

<u>Summary of Modules (M)</u>

In the CoRe module survey, half of the teachers ($N = 7$) discussed the CoRe assignment itself. The main themes related to the module were:

- The CoRe assignment prompted teachers to reflect more deeply on how they plan to bring organic and biochemistry topics into their teaching, thus allowing teachers to practice each component of PCK.
- Through the CoRe module, participants were able to bring a new, advanced chemistry topic into their high school instruction.

<u>Interaction (I)</u>

Two teachers discussed interactions in relation to the CoRe assignment. Two teachers expressed that they could further develop their teaching confidence by observing colleagues or discussing pedagogy with other teachers.

- Asking "my colleagues…what works or does not work for them. I would probably actually have to watch one of my colleagues present this first or watch a video of the presentation." – Teacher 38
- "I believe having more opportunity to talk to peers and instructors about the topic (rather than just a few discussion boards and learning from videos and texts) would give me more confidence." – Teacher 30

These teachers emphasized the importance of interacting with colleagues and learning from others in a professional setting.

<u>Examples of Reflection (R)</u>

Many teachers used the CoRe module survey to reflect on their experience creating a CoRe for their chosen topic. Several participants discussed their process of thinking through their lesson in a way that would best support student learning.

- "The [CoRe] questions about student difficulties made me try to think like a teenager to anticipate problems and misconceptions." – Teacher 40

- "Making this CoRe for my concept… was challenging in the sense that I had to try and predict potential outcomes in my classroom." – Teacher 11
- "Writing the CoRe…made me consider what I would focus on or skip next year for better student comprehension." – Teacher 25
- "I think the ability to make organic and biochemical connections to content will really pique students' interest and improve retention overall." – Teacher 30

Some teachers discussed the need to adjust their instruction for the high school setting through lesson design, selecting which aspects of a concept to bring into their instruction, or reflecting on the standards. These comments focus primarily on the curriculum organization and resource components of PCK.

- "It was a bit difficult to design and find resources for lessons that would be appropriate for the high school setting." – Teacher 22
- "It's an important topic that is a small chunk but belongs in a larger and important context. Trying to visualize just this topic almost outside of its greater context was a challenge. Thinking of alternate ways to assess mastery without needing too complex of an explanation was also tough." – Teacher 36
- "I plan to use this right away, but I like to think about how things fall into the big sequence of the year. This lesson might not fit into our first year chem class - unless we have some extra time." – Teacher 27
- "It can be challenging to find the write standard to tie something to. I don't really like the way NGSS is presented in its physics/chemistry combined format. I do like that the math component is clearly spelled out for those who would otherwise question my attachment to math proofs with numbers and units on everything, but

I feel like too much is implied instead of stated. The main standards at the top are vague and then there is more detail at the bottom." – Teacher 43

In addition, some participants used the CoRe module survey to think about how they think about their facilitation or resources for lessons before instruction. A couple of examples are given below.

- "I like to give myself guiding or probing words to help facilitate and keep the conversations around the topic going." – Teacher 11
- "I do like the fact that modeling programs are so easily available now. I still think the students can benefit from the hands on, but the computer version is more their style." – Teacher 43

Participants were also able to think about how they approach teaching and how their development of a CoRe, or any lesson plan, requires deep reflection.

- "Over time and with the practice that is needed and deeper understanding of the concept myself, I can reflect on this exercise and modify things that work and don't work to refine my teaching to help students. But that is what teaching is supposed to be about anyway, isn't it?" – Teacher 38
- "I am looking forward to implementing my ideas from the CoRe assignment, then reflecting on how I could be better for my students!" – Teacher 11
- "I think that this module has helped to remind me that a good lesson is planned from several different angles. It's ok to think about 'what do students not need to know yet.' It's important to always consider 'why am I teaching this' always. It really focuses on the objective of the lesson." – Teacher 36

Summary of Reflection (R)

The CoRe assignment allowed participants to reflect on their teaching of a specific CHEM 775 topic. The main themes for reflection were:

- The CoRe gave teachers an opportunity to apply advanced chemistry content knowledge to a high school chemistry teaching context, which required participants to rethink how they would approach lesson design.
- Participants practiced multiple components of PCK, such as KoT, KoCO, or KoR, through their creation of a CoRe.

Codebook 4

Codebook 4 then allowed me to break down the teacher statements by source of motivation. Each comment was assessed to determine the focus of the comment, either focused on the participant's learning, their students' learning, or the participant's teaching. Coding frequencies are displayed in Table 193.

Table 193. Module Survey Coding Frequencies for Semester 3 CoRe – CB4

Code	**Abbreviation**	**Total Number of Teachers Represented (*N* = 14)**	**Percentage of Total Responses (%)**
Learning-focused	L-f	14	100
Student-focused	S-f	11	78.6

Teaching-focused	T-f	14	100

All participants shared comments focused on their own learning and teaching. Many participants (*N* = 11, 78.6%) also discussed motivations regarding their own students. The CoRe module survey gave participants an opportunity to reflect on their own learning in CHEM 775. Some examples of learning-focused statements are given below.

- "I felt that learning the content for myself was difficult. Mostly due to the difference in my personal learning style and what the professor was offering as material." – Teacher 39
- "It was challenging to the extent that I am not anywhere near as familiar with some of the organic content as I have been with earlier material in other courses and even in the first part of this course." – Teacher 2
- "This course has given me more in-depth knowledge of energy metabolism." – Teacher 40

All participants also gave comments motivated by their teaching. A selection of teaching-focused statements is given below.

- "While I do not teach these subjects specifically, this CoRe assignment is just one example of content in the course that I am able to use as examples in my own curriculum." – Teacher 30
- "I haven't really planned out a lesson about IUPAC naming before, so this module gave me a chance to sit down and work through the challenges of teaching this concept." – Teacher 20

- "This was challenging for me because I don't teach this concept in any of my classes. It was a bit difficult to design and find resources for lessons that would be appropriate for the high school setting." – Teacher 22

A majority of teachers (78.6%) shared student-focused comments. Some examples are given below.

- "Writing the CoRe as I taught was very easy, and it made me consider what I would focus on or skip next year for better student comprehension." – Teacher 25
- "I do think that my struggle with the topic might help me understand where students will get confused." – Teacher 20
- "I am looking forward to implementing my ideas from the CoRe assignment, then reflecting on how I could be better for my students!" – Teacher 11
- "I had to work in this course to understand but I was able to use some of the strategies I prepared for myself to learn for my students." – Teacher 6

Summary of Module Survey – CoRe

The CoRe module survey allowed participants to discuss their experience completing a CoRe for a CHEM 775 concept. All participants shared motivations relating to their own teaching and learning. Most teachers (78.6%) also discussed student-focused motivations, but many participant comments emphasized reflection on what they had learned and how they would apply this new knowledge to their teaching. The main themes from the Fall 2022 CoRe module survey were:

- The CoRe exposed gaps in teachers' confidence and chemistry content knowledge; however, most participants discussed how the CHEM 775 course filled gaps in knowledge and helped teachers develop new skills that strengthened their teaching confidence. By improving their KoSc and combining this knowledge base with their KoT, teachers demonstrated improvements to the quality of their overall PCK.

- After taking the CHEM 775 course, teachers expressed increased KoSc, KoCO, KoT, and KoR, which reveals improved PCK quality.
- The CoRe allowed participants to consider how they could bring advanced organic and biochemistry concepts into their high school classrooms. By reflecting on their KoSc and KoT, teachers demonstrated improved PCK quality.

This was the third iteration of the CoRe assignment, although many participants were new to the program and experienced the module for the first time. Nevertheless, all teachers were able to develop a well-rounded CoRe for an organic and biochemistry concept using a combination of PCK bases. This module assignment gave teachers an opportunity to reflect on how they could bring knowledge gained from the CHEM 775 course into their current teaching context, demonstrating how professional development occurs in the MS program.

Teaching Script

In Fall 2022, the Teaching Script was also administered in CHEM 774: Kinetics, Nuclear, & Electrochemistry. The Teaching Script was analyzed using Codebook 2 to assess participants' PCK. Table 194 displays the codes from Codebook 2 that appeared in the Semester 1 Teaching Script.

Table 194. Teaching Script Coding Frequencies for Semester 3 – CB2

Code	**Abbreviation**	**Total Number of Teachers Represented (*N* = 12)**	**Percentage of Total Responses (%)**
Knowledge of science	KoSc	12	100
Knowledge of goals	KoG	12	100
Knowledge of students	KoSt	12	100
Knowledge of curriculum organization	KoCO	12	100
Knowledge of teaching	KoT	12	100
Knowledge of assessment	KoA	3	25
Knowledge of resources	KoR	12	100

Just like the CoRe assignment, the Teaching Script assignment was created to gain information about participants' PCK. Like the CoRe, many of the Codebook 2 codes were present in participant responses, as all teachers should possess prior PCK.

For Semester 3, a few teachers submitted an interpretation of the assignment that departed from the assignment guidelines. For consistency across semesters, these submissions have been omitted from analysis.

Examples of KoSc

The first component of PCK represented in the Teaching Script is KoSc, which includes science content, scientific practice, the nature of science, and scientific progress.[41] Participants identified a challenging topic from CHEM 774 that they would like to bring into their current teaching. The most commonly chosen topics were redox reactions ($N = 8$), nuclear chemistry ($N = 3$), or determining reaction order ($N = 1$). These topic choices cover each of the main themes of the CHEM 774 course: electrochemistry, nuclear chemistry, and kinetics. When describing the reasoning behind their topic choice, several teachers demonstrated their KoSt by discussing student struggles with concepts and math skills or potential misconceptions. These comments will be discussed in the KoSt section below. Some teachers discussed how their own learning may impact their instruction, and therefore student learning.

- "Although I felt confident with the concept of oxidation and reduction, I struggled to determine whether a reaction would be spontaneous and to set up the math correctly with some of the more complex systems. I know that how an instructor presents content to students makes a difference in their ability to understand and apply concepts taught. I would like my students to have a good foundational understanding for future academic instruction." – Teacher 9
- "Identifying…which species is oxidized/reduced and the justification for how you know which is occurring…is hard to teach because it became so simple to me and I rush through it. I wanted to focus on it more for my teaching script because this class reminded me that it is fundamental for so much of chemistry." – Teacher 36

One teacher described the challenge of teaching their students skills while also allowing for time to explain their real-world importance. This statement connected to their KoG.

- "I think that teachers, myself included, spend a lot of time trying to get students to be able to perform a skill or complete a task. This leaves us little time to be able to get them to an understanding of why or how they will be using this in their lives. Our education has been so focused on performance that I have found it difficult in recent years to show students things beyond the ability to complete a task." – Teacher 6

Participants also stated that having a lack of experience influenced their topic choice for their Teaching Script.

- "Redox reactions…would be difficult for me to teach for a couple of reasons. First, it has been a while since I have covered these in my chemistry classroom. Second, it is not a topic that I am very familiar with. Trying to keep everything organized with redox reactions can be challenging as well." – Teacher 11
- "I have never taught electrochemistry since it typically comes at the end of the school year. I do not know how the students will react to the material and whether or not it'd be too challenging for their current level of understanding." – Teacher 25

Only 58.3% of the teachers ($N = 7$) provided examples of their prior knowledge, all but one of the teachers ($N = 11$) gave examples of additional knowledge they could share with the more curious student. A selection of responses related to teachers' content knowledge is given below.

- “I know that the neutron to proton ratio can help predict if an isotope is stable or unstable and what decay mode the isotope may decay to produce. I also know that this isn’t a perfect science and some isotopes are exceptions to the rule.” – Teacher 35
- “The dry cell is the most common battery. Zinc atoms oxidize on the surface of an anode by giving up electrons to become cations. The anode becomes more negatively charged than the cathode due to the electrons left behind by zinc. If the cell is connected to a circuit. The electrons move to a carbon rod to create a new current.” – Teacher 37
- “Roughly half of a radioactive sample decays each half-life. The half-lives are consistent for each substance, but every atom decays at a random time. For example, if the half-life is 10 minutes, roughly half the sample will decay in 10 minutes, but some will decay faster than others.” – Teacher 31

Teachers then shared what they viewed to be the fundamental components of their chosen concept. A selection of responses is given below.

- “The fundamental concepts are assigning oxidation numbers and the definition of oxidation and reduction. When students can correctly assign oxidation numbers and apply the definition of losing and gaining electrons for oxidation and reduction, respectively, they will show proficiency.” – Teacher 36
- “The fundamental components of the concept are: understanding of oxidation-reduction reactions - identifying ½ reactions; identifying cathode and anode in a galvanic/voltaic cell; analyzing and interpreting standard reduction table; predicting electron flow.” – Teacher 9

- "I believe the most important takeaway from this topic is the writing of overall reactions. I believe this because the fundamental components that make up the concept have to be learned and understood in order to complete it. The fundamental concepts include oxidation numbers, half-reactions, and acid versus base solutions." – Teacher 11

<u>Summary of KoSc</u>

Through the Teaching Script assignment, teachers were able to relate their content understanding of electrochemistry, kinetics, and nuclear chemistry topics. Participants shared the content knowledge they would bring into their teaching. The most common themes for KoSc were:

- Many teachers chose their topic due to student struggles they have observed in the past, which aligns with their KoSt. This combination of knowledge bases demonstrates PCK.
- Teachers are aware of how their own learning challenges will impact their ability to teach effectively, which in turn will affect student learning. Because of this awareness, participants intentionally chose a topic for their Teaching Script in order to perfect their content knowledge and lesson design prior to introducing these topics to students.
- Participants were able to demonstrate their own chemistry content knowledge while stating the learning objectives they had for their students in regard to foundational concepts.

Examples of KoG

The next code for the Teaching Script assignment relates to KoG, which may include learning goals for scientific literacy, real-life application, and integrated understanding.[41] All teachers but one ($N = 11$) shared why they thought it was important for their students to learn their chosen concept. Most teachers found it important for their students to understand the topic's real-world applications.

- "Upon learning more about redox reactions, I believe that they play an important role in our lives, and these reactions are all around us, if we know where and how to look for them. I believe this is an important concept for students to understand because of all the real-world connections that can be made." – Teacher 11
- "Most of the processes in our lives involve some sort of redox or transfer of charge. I also think for the non-STEM people this is the most common thing they will run into." – Teacher 6
- "…Electrochemistry helps students understand the relationships between electricity and chemical reactions. Galvanic cells are a physical application of oxidation reduction reactions." – Teacher 37
- "It's important for students to understand that chemical reactions can create energy, energy that is used to power their electronics, vehicles, biological systems, and more." – Teacher 25
- "Students need to understand half-lives because there are radioactive isotopes they encounter daily. Understanding what a half-life is, how it is determined, and what that means in terms of safety will help students gain a better understanding of how the world works." – Teacher 31

Teachers also described their goals that students should understand fundamental scientific concepts that are relevant to everyday life.

- “Students should understand the concepts of anodes and cathodes within the context of energy producing redox reactions.” – Teacher 37
- “This concept is important in understanding how chemical energy can be converted to electrical energy.” – Teacher 9
- “Students should be able to identify different uses for different isotopes as well as be able to explain why different decay particles have varying penetrating power and therefore varying risks.” – Teacher 35
- “It is important for students to know this concept so that they can analyze the particle behavior at the molecular level.” – Teacher 43
- “Students need to understand and identify reaction types to predict products and determine what substances will and won’t react.” – Teacher 36
- “Students will learn how to collect and analyze the data and understand how this concept and data analysis is used in real life.” – Teacher 29

Participants mentioned that their chosen topic would allow students to prepare for future education, careers, and standardized testing.

- “Students will need to understand this concept for the AP Chemistry exam. While there aren’t that many questions on the exam, having a basic understanding will also make a college level chemistry course easier for students.” – Teacher 22
- “These concepts also may come up in college physics or chemistry classes that students take for their future careers.” – Teacher 31

- "An understanding of galvanic cells is essential for students who plan to have a career in the sciences. The application for reactions generating energy is fundamental for engineering, chemistry, physics and biochemistry/biomedical engineering." – Teacher 37

For the next prompting question of the Teaching Script, all participants shared real-world examples related to their chosen topic. A selection of responses is given below.

- "Some real-world connections I can use for redox reactions include respiration, photosynthesis, combustion, corrosion, fuel cells, and how batteries operate." – Teacher 11
- "Rust and corrosion in the workforce, strong oxidizers in the beauty industry, and electrochemical cells (batteries) in the trades." – Teacher 6
- "One real-world connection is radon gas in basements. We can discuss how radon is radioactive and the importance of getting your basement checked periodically for radon gas. We can discuss where radon comes from, how long its half-life is, and how this gas affects our health." – Teacher 31

Summary of KoG

Teachers revealed their goals for teaching a challenging topic from CHEM 774 by describing the importance of learning the concept and some real-world connections that are relevant to students' lives. The most common themes for KoG were:

- All participants were able to give multiple real-world connections to their chosen topic, showing higher-order thinking associated with a CHEM 774 topic. Most participants described the relevance of these examples to their students' lives, demonstrating their KoSt and, therefore, PCK.

- Teachers are aware of the importance of preparing students for future learning, including formal education, careers, and informal lifelong learning.

Examples of KoSt

The next code is KoSt, which may focus on different learning levels, needs, interests, prior knowledge, ability, learning difficulties, and misconceptions.[41] All teachers chose to teach their challenging topic to a general chemistry course ($N = 4$) or to an advanced chemistry or physics class, such as AP or Honors ($N = 9$), with one teacher choosing to include the topic in their general physics course. Two teachers included above listed both advanced and general chemistry courses as the student learning context.

Many teachers demonstrated their KoSt when explaining their topic choice. Teachers were able to identify concepts or that may be more challenging for their students to understand.

- "I think students may also have trouble with the standard reduction table and knowing which reaction to reverse to oxidation." – Teacher 40
- "Students struggle with why different isotopes decay to form different decay particles, such as alpha, beta, and positron particles." – Teacher 35
- "Truly understanding what a half-life is and how it is determined is difficult for students. I think this is due to the way the information is taught and to the complexity of the subject matter." – Teacher 31

Some teachers described that math and data interpretation can be difficult for their students.

- "The math can be challenging for some students. Dealing with logs, natural logs, antilogs, and antinatural logs tends to confuse some students. They typically struggle with typing the information into their calculators correctly." – Teacher 31
- "I always find the transition from mathematical calculation of order to graphical determination of order to be a tough leap for students. So many of them are good at following through with plugging numbers into an equation and calculating through to a numerical answer that presenting the same information in graphical form poses some difficulty when it becomes the only source of information for determining order. Even though the students' math skills seem to be more sophisticated than one might expect if you look at the name of the current math class they are taking, they often learn the concepts and processes of current material without thinking of its application." – Teacher 43
- "The reason for it is a lot of my students struggle with analyzing and reading graphs." – Teacher 29
- "The Nernst equation would be the most difficult topic to teach, because it covers complex concepts and involves math that is challenging for most high school students." – Teacher 22

One teacher chose their topic due to potential misconceptions that could arise during instruction.

- "It is a conceptual topic with a few misconceptions students are prone to making." – Teacher 37

In the Teaching Script itself, teachers were prompted to identify misconceptions that they expect to occur when teaching their chosen topic. A selection of responses is given below.

- "Students may be prone to thinking that electrons move through the salt bridge instead of ions." – Teacher 37
- "I believe the most common misconceptions are going to be with labeling and identifying the elements in the redox reactions. For example, with labeling, the element that is oxidized is known as the reducing agent, and the element that is reduced is the oxidizing agent. I believe students will confuse this at the beginning of the lesson and could be a potential struggle for students throughout the lesson." – Teacher 11
- "I expect students to think that all the atoms decay at the same time. Therefore, half the atoms decay when the atom reaches its half-life, instead of the atoms decaying randomly throughout the time period for 1 half-life." – Teacher 31

Teachers then shared reactions or questions they would expect from their students during this lesson. Based on prior experiences with students, teachers share which questions they expect from students related to CHEM 774 topics. Some questions related to the content itself.

- "Are all chemical reactions redox reactions? Where else, in the real world, can we see this happen?" – Teacher 11
- "What would happen if you were at equilibrium and Q=K? How much can the concentration change the E? Is this why batteries go dead?" – Teacher 22

- "What would happen if the salt bridge is used up or removed? Why do batteries die? Why can't you just reverse the process?" – Teacher 25
- "Are nuclear power plants safe? How much radiation can we be exposed to before we are in danger of developing cancer or other diseases? How do scientists determine the half-life of a radioactive isotope? How do scientists use radioactive substances for dating objects or people?" – Teacher 31
- "How do scientists know the half-lives of substances that take years to decay? What happens to the substance when only 0.0000000001 of it is left?" – Teacher 29
- "My students have already shown interest in batteries and how they work. Therefore, I think a follow up question will be, 'Can we make a battery?' Which of course, the answer will be yes!" – Teacher 37

Other questions pertained to the relevance of the topic or the purpose of learning the content.

- "Will this be on the test? Why do I need to know this?" – Teacher 11
- "When am I going to use this in my life? I don't need to understand electrochemistry to use electronics." – Teacher 25

In terms of reactions to the lesson, some teachers predicted student attitudes and behavior based on prior experiences.

- "Students will complain that it is too difficult as soon as I show them the rules for determining overall redox reactions. Some will likely get frustrated with not understanding it and could potentially shut down. Shut down, in the same sense as giving up." – Teacher 11

- "I anticipate that curious students will want to know more about cutting edge battery technology in addition to galvanic cells. Students will want to know which other metal combinations can produce electricity." – Teacher 40
- "A lot of initial confusion and claims they don't understand but by the end, they somehow do well enough on the test to show me they got the main points of the topic." – Teacher 25
- "Based on prior experience, I expect students would be excited by this topic. It isn't covered in Honors Chemistry so they will be excited to learn a new application of redox reactions." – Teacher 37

Other teachers shared anticipated student reactions to the mathematical components of their chosen topics.

- "My experience is that students may memorize a mathematical process with little to no understanding of what it means. A good example of this is density. Students may be able to plug and chug a mathematical answer but might struggle to analyze if an item would float or sink." – Teacher 9
- "Some students may understand how to plug the numbers into the equation provided but struggle with the conceptual components involved. Some students will struggle with the math but understand the conceptual concepts." – Teacher 31
- "I expect, based on past years, students to be slow on the uptake because they tend to overthink these steps. I expect there to be hesitancy because it seems like it is more work to be done on an equation and sometimes students don't seem to want to dive into the minute details." – Teacher 36

One teacher discussed the importance of preparing their students for certain topics in light of past experiences.

- "Hopefully, they will be impressed to see how science is used in real life. Last year, I had a religious student who was very upset when we talked about Earth's age, so I need to make sure to give the warning before we start this unit about what will be covered in it." – Teacher 29

One teacher stated that, having never taught their chosen topic, they were unable to predict student reactions. This may indicate a gap in their PCK, particularly their KoSt.

<u>Summary of KoSt</u>

In the Teaching Script, participants demonstrated their KoSt by anticipating potential misconceptions, questions, and reactions to instruction of their chosen topic. The main themes for KoSt were:

- All teachers were able to identify misconceptions associated with their chosen topic, demonstrating knowledge of both science and students, which reveals teachers' PCK.
- Many participants chose their challenging topic because they anticipated students struggling with the concepts themselves, mathematical processes, or data interpretation. The Teaching Script assignment allowed participants to think through their lesson plan and prepare for anticipated challenges.
- Most teachers were able to predict students' behavior during instruction, including attitudes, questions, and confusion.

Examples of KoCO

The next code relates to KoCO, which may include knowledge of state and local standards.[41] All participants but one identified connections between their chosen topic and what concepts they currently teach. Some examples are given below.

- "We teach about bonding and atoms and I feel like this unit about redox reactions would fit nicely during or after our normal chemical reactions unit." – Teacher 6
- "This topic fits in with the overall concepts of oxidation-reduction and is a natural extension of single replacement reactions covered in our textbook." – Teacher 9
- "The Nernst equation is one of the AP Chemistry standards. I would teach it during the electrochemistry unit." – Teacher 22

After discussing how their concept ties into what they teach, teachers are asked to identify relevant standards. Teachers included a range of standards, including those from the NGSS ($N = 8$), AP Chemistry or Physics guidelines ($N = 6$), and state-specific standards ($N = 1$). Some teachers included multiple groups of standards; for example, some teachers included relevant NGSS standards and AP skills.

To conclude the curriculum organization section, teachers were asked to make decisions about what they planned to teach about their chosen topic based on what they felt their students needed to know. A selection of responses is given below.

- "Most high school students have been exposed to point-slope and some even have been exposed to integrals (depending on their current math course)…Many of my students are only aware of the fact that a line has an equation. They need to be helped/introduced to the fact that the line is analogous to the rate law equation and that you can tell important information from it beyond the standard (x,y) points that are graphed upon it." – Teacher 43

- "Students need to be able to explain oxidation and reduction in terms of gaining or losing electrons. This would have been covered in the different types of chemical reactions unit." – Teacher 25
- "Students need to recognize monatomic and polyatomic ions as well as the charge for common ions." – Teacher 36
- "I think the students need to know what it means to be oxidized and reduced and how to decide if a reaction will happen based on reduction potentials." – Teacher 6

Summary of KoCO

Participants demonstrated their KoCO by identifying relevant standards and making decisions about what to teach their students about their chosen concept. The most common themes for KoCO were:

- All teachers were able to integrate their chosen topic into their existing curriculum and were aware of the standards that best related to their topic.
- Teachers were able to state intended learning outcomes of an advanced chemistry concept based on their students' prior knowledge and learning level.

Examples of KoT

The next code is KoT, which involves the discussion of teaching methods and activities.[41] Participants shared teaching procedures related to their chosen topic and their timeline for covering this concept. For their Teaching Script, all teachers decided to use direct instruction or videos (*N* = 12), with most also choosing to include practice problems ($N = 9$). Many teachers also incorporated lab activities or demonstrations into their lesson plan ($N = 6$). The final categories of teaching strategies mentioned in Teaching Scripts were simulations/modeling ($N = 4$), discussion ($N = 2$), and writing ($N = 1$).

Several teachers supported their description of teaching procedures by providing reasoning behind their teaching choices. A few examples are given below.

- "I try to use a multitude of teaching strategies when covering topics because I don't want the students to become uninterested in what we are doing." – Teacher 11
- "I think it would be important for students to use models of atoms and charges. It is helpful for them to physically see a charge change when something is reduced or oxidized and then know that it has to move to another atom." – Teacher 6
- "I like when students construct their own definitions and concepts rather than being directly instructed about them. It seems to allow for more long-term memory translation than direct instruction would." – Teacher 35
- "Warm up - to activate students' prior knowledge about graph reading and see what learning gaps students have." – Teacher 29

Many teachers created a lesson plan that would take up one to three class periods during a longer unit, while a few teachers created Teaching Scripts that would take up several days. Teachers' timeline for the topic depended on the complexity of the concept, but the majority of teachers were able to plan and predict a timeline for their lesson.

Most teachers ($N = 10$) described how they would address misconceptions during instruction. In order to correct misconceptions, many teachers chose to return to direct instruction or modeling to review material (*N* = 8). Additional methods included practice problems (*N* = 2), simulations (*N* = 1), and demonstrations (*N* = 1). When discussing how they would address misconceptions, some teachers demonstrated their KoSc by describing the specific corrections they would make to students' conceptions of the new topic. A few examples are given below.

- "Elements with 83 or more protons have no stable isotopes and some elements like Be-9 has only one stable isotope." – Teacher 35
- "In addition, with the practice I will introduce students to the acronyms OIL RIG and LEO GER. OIL RIG means oxidation is losing and reduction is gaining. LEO GER means losing electrons is oxidation and gaining electrons is reduction." – Teacher 11
- "The salt bridge is used to provide cations or anions to the solutions." – Teacher 25

Summary of KoT

Teachers showed their KoT by outlining their teaching procedures and explaining how they plan to address student misconceptions. The main themes for KoT were:

- Participants demonstrated multiple components of PCK by describing teaching procedures (KoT), making decisions about what and when to teach (KoCO), and correcting misconceptions (KoSc). Through the Teaching Script, participants were able to demonstrate high quality PCK by combining knowledge bases and explaining the reasoning behind their teaching choices.

- Each participant utilized multiple teaching strategies in their lesson plan of an advanced chemistry topic and most teachers described the reasoning behind their teaching choices, which highlights their strong KoT as a component of PCK.

Examples of KoA

The next code is KoA, which details teachers' knowledge of formal and informal assessments and feedback.[41] The Teaching Script assignment did not ask participants to detail their assessment methods. Some teachers described formal and informal assessments that they included in their teaching procedures section of the core. These assessment methods included tests or quizzes (*N* = 3), discussions (*N* = 2), direct questioning (*N* = 1), and writing (*N* = 1). Three teachers explicitly stated these assessment methods, while eight others included methods that assess student learning but did not specifically describe them as assessment methods. This may reveal a gap in some participants' PCK due to a gap in their KoA.

Summary of KoA

Unlike the CoRe, the Teaching Script assignment did not prompt teachers to describe how they would assess student understanding. The main themes for KoA were:

- Only three participants (25%) explicitly described assessments in their teaching procedures, which demonstrates that these teachers include assessment as a component of their teaching process. Eight other teachers included assessment methods in their teaching procedures, but did not explicitly identify them as assessments which potentially reveals a gap in their PCK.

Examples of KoR

The final code in Codebook 2 discusses KoR.[41] In the Teaching Script assignment, teachers were asked to identify materials that they would provide to students who wanted additional instruction. All participants provided descriptions or links to resources like readings (including journal articles) ($N = 9$), videos ($N = 6$), lab activities ($N = 2$), and additional practice problems ($N = 2$).

Earlier in the Teaching Script, one teacher discussed a resource provided by their state that is relevant to their Teaching Script lesson. This resource prompted the teacher to choose their specific topic, which also demonstrates their KoR.

- In [state], students are provided Table N (see below) that lists common radioactive isotopes and their decay mode but there seems to be no rhyme or reason why the isotopes decay in those modes. This makes the task of writing and evaluating nuclear reactions abstract and algorithmic with no real understanding of what is happening in the nuclei of the atoms." – Teacher 35

Summary of KoR

The main theme for KoR was:

- Teachers are knowledgeable about specific readings, videos, and activities they can provide to students outside of the learning materials involved in their lesson plans. This demonstrates teachers' awareness of educational materials related to their chosen topic, which contributes to their KoR and improves the quality of their overall PCK.

Summary of Teaching Script Data

Through the Teaching Script module, most teachers were able to demonstrate each component of PCK. Fewer teachers explicitly described their KoA, but all teachers provided details of the remaining six components of PCK. Participants employed multiple teaching strategies for their instruction of electrochemistry, kinetics, or nuclear chemistry concepts. By combining their KoSc and KoT, teachers demonstrated improved PCK quality. The Teaching Script allowed teachers to reflect on a challenging topic from CHEM 774 and the main themes were:

- Participants' topic choice related to their KoSt by describing how students have struggled with the topic in the past. Participants used the Teaching Script assignment to hone their own content and pedagogical knowledge and prepare an effective lesson that would support student learning. By combining their KoSc, KoT, KoCO, and KoSc, teachers demonstrated improved PCK quality.
- All participants were able to identify real-world connections related to their chosen concept, which demonstrated their KoG as a component of their overall PCK. Additionally, teachers explained the importance of emphasizing the relevance of chemistry topics to prepare students for future education/work.
- Teachers were able to anticipate student reactions to the content, as well as potential misconceptions. Participants also used their KoSc to address misconceptions and describe how they would adjust their teaching in order to correct student understanding. Teachers combined their KoSc, KoSt, and KoT, which again demonstrated higher quality PCK.

- Because only a quarter of the participants explicitly described their KoA, there may be a gap in teachers' PCK in regard to assessment. However, most teachers informally assessed their students throughout the lesson without identifying these methods as assessments.
- Teachers are aware of a wide variety of supplemental materials that they can provide to students who need more support or would like to learn more about their chosen topic. In this Teaching Script, participants demonstrated a strong KoR, which supports the higher quality PCK described above.

Due to the breadth of topics covered in CHEM 774, teachers were able to choose from a wide variety of chemistry concepts to best fit their teaching needs.

Module Survey – Teaching Script

After completing the module, teachers were invited to complete a survey about their experience creating a Teaching Script for their topic. Nineteen teachers completed the Teaching Script module survey in Fall 2022. In the survey, participants were asked if they would feel comfortable teaching their chosen topic without preparation. Of the twenty teachers, 9 (45%) would not feel comfortable, 6 (30%) would feel comfortable, and 5 (25%) would feel comfortable teaching without preparing beforehand but did not think it was good teaching practice or did not feel fully comfortable. When asked about their confidence level on a scale of 1 to 6 for teaching their concept, the average confidence score was 5.048. Upon creating a Teaching Script for their topic, 6 teachers (30%) did not find it challenging and 10 (50%) did find it challenging, with 4 of these teachers finding only some aspects to be challenging. The Teaching Script module survey was coded using all Codebooks 1, 3, and 4.

Codebook 1

Coding frequencies for Codebook 1 can be found in Table 195.

Table 195. Module Survey Coding Frequencies for Semester 3 Teaching Script – CB1

Code	**Abbreviation**	**Total Number of Teachers Represented (*N* = 20)**	**Percentage of Total Responses (%)**
Attitudes	A-c	8	40
Knowledge	K-p	3	15
	K-c	11	55
Skill	S-p	2	10
	S-c	3	15
Teaching	T	20	100
Background	B	3	15
Experience	E	1	5
Goals	G	1	5
Feedback	F	5	25
Modules	M	4	20
Interaction	I	2	10
Reflection	R	18	90

Examples of Attitudes (A-c)

Eight of the teachers (40%) shared statements focused on their attitudes toward learning or teaching CHEM 774 topics or using their Teaching Script lesson. Some teachers expressed positive attitudes, including excitement, when discussing bringing new strategies and knowledge into their classrooms.

- "I love that I have even more detail for those students who have questions…It will be fun to show them what I have done this semester." – Teacher 43
- "I've never taught electrochemistry before and now I am excited to do so." – Teacher 40
- "I enjoyed working on an assignment that will help me showcase what I have learned and create a resource to utilize in my classroom…The depth in which we covered concepts made me feel more comfortable explaining at a higher level." – Teacher 37

Two teachers discussed attitudes associated with the learning that took place in the CHEM 774 course.

- "I found learning about this concept to be enjoyable." – Teacher 11
- CHEM 774 "has made me more confident in my overall understanding of electrochemistry and its importance within a larger scheme of chemical concepts." – Teacher 36

One teacher discussed their confidence teaching topics that they learned in CHEM 774.

- "I feel confident covering the basics of a galvanic cell. I also feel confident with an explanation of an electrolytic cell and the application of this process." – Teacher 9

Two teachers shared attitudes regarding challenges they faced in the course, including low confidence or understanding.

- Creating a Teaching Script "is particularly difficult because my confidence in the subject is still emerging." – Teacher 9
- "Throughout this course I have really felt lost most of the time." – Teacher 39

Two teachers described attitudes about using their Teaching Script lesson in the future.

- "I am curious to see how [using my Teaching Script] works out and how true I stay to the script." – Teacher 42
- "I'm glad I have this lesson available and ready should I have time for it in the future." – Teacher 9

<u>Summary of Attitudes (A-c)</u>

Some teachers (N = 8) shared their current attitudes about learning and teaching electrochemistry, kinetics, and nuclear chemistry concepts through the Teaching Script assignment. The most common themes for attitudes were:

- The Teaching Script assignment allowed teachers to prepare a lesson on a CHEM 774 topic that some have never taught before. These participants expressed excitement toward having increased confidence and knowledge on a topic they want to bring into their teaching.
- Two teachers described having "emerging" confidence or feeling "lost most of the time" in the course; however, these teachers exhibited qualities of resilience by sharing areas where they could use these attitudes to improve their confidence or teaching in the future.

Most teachers shared positive attitudes about bringing CHEM 774 topics into their classrooms. Their bridging of the learning that took place in the MS program and the teaching that occurs in their classrooms demonstrates PCK through focusing on KoG, KoT, and KoSt.

Examples of Knowledge (K-p and K-c)

Three teachers discussed their prior knowledge. One teacher indicated their content knowledge baseline prior to taking CHEM 774.

- "I knew almost nothing about the topic before beginning this class." – Teacher 40

Two of the three teachers discussed changes in their content knowledge by describing the level of their prior knowledge in comparison to the knowledge they gained through the CHEM 774 course.

- "Considering that I was a typical college student [in 1989], I was not retaining everything taught…The content of this course has expanded my understanding of electrochemistry vocabulary, modeling conventions, and calculations related to electrochemistry." – Teacher 9
- "When I taught AP chemistry several years ago, I struggled through some of the notes because I didn't quite understand what was going on. This class has helped me out immensely in what exactly is going on and why…I have a much better understanding of electrochemistry." – Teacher 25

Over half of the teachers (55%), including the two teachers above, discussed their current level of knowledge after taking CHEM 774. A selection of responses describing teachers' chemistry content knowledge is given below.

- "Our lesson on the Nernst equation helped refresh my memory and give me some experience working through the problems." – Teacher 22
- "It has given me a greater understanding, not only of the concept of redox reactions, but the overall larger picture as well." – Teacher 11
- "I have gained a better understanding of nuclear topics. I learned a new equation for half-life." – Teacher 31
- The CHEM 774 course "has also given me more knowledge of science history." – Teacher 4

Some teachers mentioned feeling more comfortable fielding student questions after gaining a better grasp of the content. This highlights improved KoT and KoSc, which indicates improved PCK.

- "If students ask questions and we go off script, I will feel more comfortable knowing I have a stronger background in the material now." – Teacher 37
- "I have also gained a better understanding of nuclear physics and I hope that I will be able to provide better or more detailed answers to my students questions that go above and beyond the scope of my class." – Teacher 31
- "I love that I have even more detail for those students who have questions." – Teacher 43

<u>Summary of Knowledge (K-p and K-c)</u>

Many teachers described the knowledge they gained through the CHEM 774 course. The most common themes for knowledge were:

- Teachers expressed gaining more content knowledge through the CHEM 774 course, including an improved understanding of electrochemistry, kinetics, and nuclear chemistry concepts. Therefore, teachers improved their KoSc and overall PCK.

- Teachers discussed how their improved content knowledge would lead to improved teaching, especially in regard to answer student questions effectively. Teachers demonstrated their combination of KoT and KoSc, which shows higher quality PCK.

Examples of Skill (S-p and S-c)

The skill that two participants described related to pedagogical skill, especially in regard to how teachers communicate scientific information to their students.

- "I have taught nuclear physics before. I just don't feel like I have done a good job explaining what a half-life is and how it is determined…I hope that I will be able to provide better or more detailed answers to my students' questions that go above and beyond the scope of my class." – Teacher 31
- "Before this program, I didn't really think about what students might find hard about a topic, such as when I taught rate law and equilibrium for the first time several years ago. Now, I take the time to think about necessary prior knowledge, potential issues, and how to help students understand the concept better with other resources." – Teacher 25

One teacher felt that they would become more confident teaching their chosen topic by having "more time to work with the Geiger counter. The old ones in my room are not working and I'm not sure yet if they are broken or if I am just not using them correctly." Improving this skill would contribute to their teaching confidence.

Summary of Skill (S-p and S-c)

The main theme related to participants' skill was:

- By gaining more content knowledge, teachers felt that they gained an improved skill of explaining concepts to students more effectively. Participants' experience in the MS program helped improve their pedagogical skill, which – in combination with improved content knowledge – demonstrates improved PCK.

Examples of Teaching (T)

All participants discussed their teaching in the Teaching Script module survey. Upon describing the challenges of creating a Teaching Script, many teachers referenced their own teaching process and how this impacted how they completed the assignment. Some examples are given below.

- "It was difficult to incorporate how I actually teach into a script, if that makes sense. When I teach, I try to use many visuals, models and tools that to translate it into a script is just difficult." – Teacher 42
- "The topic I had was a topic I currently teach in class. It just needed improvement and a new spin on it." – Teacher 14
- Creating a Teaching Script "is worth the effort because the main idea is to predict how students will respond... This is good teaching practice." – Teacher 13
- "I also found it challenging because it is difficult to know how much detail students can absorb in one class period and how to 'baby-step' into understanding this topic. I don't know if it is worth teaching a small amount of this topic without discussing Gibbs free energy, the overall concept of standard reduction potentials, the notation of $\Delta E°$, positive and negative voltages and how they relate to overall

$\Delta E°$ cell, plus a more meaningful explanation of chemical and electrical potential energy. All of these listed topics are better suited to honors or AP courses." – Teacher 9

Half of the teachers (*N* = 10) described how their teaching confidence would be positively impacted by practicing their lesson or gaining more teaching experience with the topic. Some examples are given below.

- "Practice. Teaching the subject a time or two to see what works and what the students respond to." – Teacher 40
- "Each time I teach the topic, I will develop a better understanding of student misconceptions and how to avoid/fix them." – Teacher 37
- "I think time will make me more confident. The first time doing the activity will be tough but learning from the lesson and collecting feedback will help." – Teacher 14

Participants then discussed how the content of the course has impacted their Teaching Script. Some teachers described what new content they would bring into their instruction.

- "While my Teaching Script for galvanic cells is rather simple and foundational, I feel like I would have enough mastery in the content to teach my students without confusing them too much." – Teacher 25
- The course content "helped me to get a unit together from the bits that I go over with freshmen. It has also given me more knowledge of science history which has been really engaging for my students and helped them to see some real-life connections to the material." – Teacher 4

- "I decided to use a graph from our work to show students how isotopes decay." – Teacher 35
- "I have really enjoyed reading *Strange Glow* and I plan to incorporate some of the stories from it throughout my lessons." – Teacher 31
- "I have already used material for this course in my daily teaching as well as the Teaching Script." – Teacher 42

Teachers also discussed how the course content and Teaching Script have allowed them to reflect on how they would teach their lesson over their chosen concept.

- "It gave me opportunity to explore the options on how I can teach the concept by reading discussion posts from my classmates." – Teacher 29
- The course content "has made me more cognizant of what I plan on saying and the types of questions that I ask students during the course of teaching." – Teacher 41

To conclude the module survey, participants were asked to explain how the module has transformed their teaching of their chosen topic, if at all. Many teachers stated that the Teaching Script assignment allowed them to prepare a lesson on their chosen topic that they can use in the future.

- "This module has helped create a usable lesson for my classroom." – Teacher 9
- The module "helped me create the actual lesson on the concept." – Teacher 29
- "I have an idea of how to outline this unit now." – Teacher 6
- The module "didn't transform anything it just gave me a new idea to integrate and attempt in the classroom." – Teacher 13

- "I really like to use guided inquiry activities with students prior to direct instruction." – Teacher 22
- "I feel that I will be able to teach the concept with more direction now." – Teacher 39

The Teaching Script also gave teachers the opportunity to reflect on how their students would react to the material by asking participants to anticipate student thinking.

- The module "made me think of possible student questions that I would address." – Teacher 14
- "It made me think of possible pitfalls where students could potentially have problems learning this material." – Teacher 41
- "It's always helpful to imagine how the lesson plan would go and all the problems that could arise. The questions force me to consider what the students need to know for electrochemistry, as well as possible problems that might come up, such as misconceptions." – Teacher 25

Similarly, teachers also reflected on how they would introduce the topic to best fit their students' learning.

- The module "has changed [my teaching] greatly. In the past we built a lemon battery. I still think we will build a battery of some sort, but I think the modeling piece is the most important part of students learning this concept." – Teacher 37
- "This module has given me…a way that I could introduce it that wouldn't be overwhelming for my students. It has helped me to think critically and carefully about how I want to present it to my students." – Teacher 11

Summary of Teaching (T)

All participants discussed how their experience completing a Teaching Script for their chosen topic has impacted their teaching. The most common themes related to teaching were:

- It was challenging for teachers to reflect on their past teaching experiences and script out their instruction, as well as anticipate student responses. Despite the challenge, many participants found the module useful to prepare lessons that could be used in their own classrooms and to reflect on possible student questions and misconceptions. Through the module survey, teachers demonstrated KoT, KoCO, and KoSt, which highlighted their PCK.
- Participants were able to describe what new CHEM 774 content they would bring into their instruction, which highlights their KoSc component of PCK.
- Half of the participants stated that practicing the lesson or teaching their chosen concept multiple times would positively impact their teaching confidence.

Background (B)

Three teachers discussed their educational and teaching background to explain their level of prior knowledge or experience learning or teaching their chosen topic.

- “I have been teaching a while and have a lot of experience creating lessons.” – Teacher 35
- “I began teaching Chemistry in 2014, after taking my last Chemistry course in 1989 at [university].” – Teacher 9
- “I have not covered this content since student teaching in 2016.” – Teacher 6

While one teacher felt that their teaching experience better prepared them to create lessons, the other two teachers described a gap in knowledge or practice due to their lack of recent experience with the content.

Experience (E)

One teacher described their experience preparing their Teaching Script. This teacher first explained their process of choosing a topic. They then discussed their experience learning about their chosen topic in the CHEM 774 course and how this influenced their topic choice.

- "The hardest part for me was picking a single topic area from the full course content. Once I picked a topic that would work effectively as something of significant value for my own courses at school, the dominoes began to fall, and things worked really well... I know that there were some students in our group who found it rather frustrating to re-visit that topic in several consecutive weeks, but the persistence of the group and of Instructor A in making sure everyone was as clear and confident as possible was really meaningful and powerful for all of us. That conversation and depth of understanding led to a lot more desire to build my script based on electrolysis." – Teacher 2

Goals (G)

One teacher explicitly outlined a goal they had for their own teaching, which influenced their topic choice and the direction of their Teaching Script overall.

- "My goal [for teaching half-life] was to make that information more clear to my students." – Teacher 31

Feedback (F)

Data coded as feedback was sent directly to MS program instructors.

Modules (M)

Although all responses to the module survey contained information about participants' experience completing the assignment, four teachers discussed the specific impact of the Teaching Script module.

- "I will use my Teaching Script next week when I discuss mechanisms, I am curious to see how it works out and how true I stay to the script." – Teacher 42
- "I think the Teaching Script work and the product that I ended up with is going to add more meaning to that topic and be a valuable gateway into full-strength review in the course, which is invaluable." – Teacher 2
- "This module will change the way I present this topic to my AP Chem class in the spring." – Teacher 22
- "This module has given me a starting place and a guide to teaching this concept in my classroom." – Teacher 11

The Teaching Script influenced how teachers plan to bring CHEM 774 topics into their instruction, whether by allowing teachers to think about their teaching in detail or by utilizing their Teaching Script lesson in their classrooms.

Interaction (I)

When discussing the impact of the course content on their Teaching Script, two teachers mentioned the impact of interactions they have had with fellow MS program participants. The CHEM 774 course allowed teachers to discuss teaching strategies and content with other educators and broadened teachers' perspectives on different ideas and teaching methods.

- "I am the only Chemistry teacher at my high school and the difficult part of being the only one is that there is no one to bounce ideas off of. I have enjoyed this course and even though I have made only a few of the zoom sessions, it is enjoyable to hear different methods on how people teach topics." – Teacher 42
- "Generated a great idea for myself through a discussion forum with another student." – Teacher 13

Interacting with other teachers in the MS program impacted participants' KoT and, thus, their PCK.

Examples of Reflection (R)

Almost every teacher (*N* = 18, 90%) included reflective comments in their Teaching Script module survey. Participants reflected on their experience creating a Teaching Script.

- "The biggest challenge for me was the creation of PowerPoint that would briefly, but effectively relate the main ideas of this topic to the students. I found that I kept wanting to add more and more information instead of just focusing on the few points that the students would absolutely need to have. So more than once, I found myself editing out slides that I would term 'nice to know' information." – Teacher 38
- The Teaching Script assignment "made me really think about what I say during the course of teaching this topic." – Teacher 41

- "I think organizing what I really wanted to cover was challenging, but once I figured out the organization it was more just getting it done." – Teacher 4

Teachers also reflected on how the content of the course influenced their Teaching Scripts.

- The course content "has made me think a little differently of how I deliver my content, particularly my online content so that it would be more meaningful and impactful to my students." – Teacher 38
- The course content "had made me think about how to approach topics I normally do not teach." – Teacher 14
- "The time we spent discussing the ideas of both galvanic and electrolytic cells, really digging into the questions and perspectives and means of explaining to our students was really powerful." – Teacher 2
- "The content of the course is at such a higher level than what I teach in my classroom. The content has help me better understand how my students may feel when they are in my classroom. Throughout this course I have really felt lost most of the time. It helps me empathize with my students, especially my special needs and English learning students." – Teacher 39
- "I have better ideas on how I can incorporate real-world examples. Examples that would be relevant to my students and their learning. I believe by relating it to my students, I would be able to get them to buy into their learning and hopefully instill some intrinsic motivation." – Teacher 11

Participants shared how the Teaching Script module prompted them to reflect on how they teach.

- The module "really made me reflect on what and how much information the student needs to understand the concept." – Teacher 38
- The module "has made me realize that I, the teacher, talk a lot and I need to shift my focus to more student-centered instruction. I need to build in purposeful formative assessments and maybe even less group work to get a better idea of where students are in their individual understanding." – Teacher 36

Throughout the Teaching Script module survey, participants included reflective comments on what they would like to incorporate into their lessons or goals they have for student learning. Some examples of teacher statements are given below.

- "This teaching script has given me a place to start, and now it's time for me to implement it… I will always be able to go back and learn and make my lesson better and more effective for my students" – Teacher 11
- "If I teach AP ever it will be a topic I cover, too many students take AP just for the exam and credit and I have always wanted to show them there is more to science and learning than just that." – Teacher 6
- "I think going to different industry around us and asking about reduction potentials, sacrificial anodes, and strong oxidizers/reducers would really benefit this lesson." – Teacher 6

<u>Summary of Reflection (R)</u>

The Teaching Script module allowed teachers to reflect on how they would teach their chosen CHEM 774 topic. The most common themes for reflection were:

- The Teaching Script allowed teachers to reflect on what information they wanted to communicate to students about their chosen topic, as well as how they planned to bring this topic into their instruction. These reflective comments revealed teachers' KoCO, KoT, and KoG, which all comprise PCK.

- The Teaching Script gave teachers an opportunity to reconsider their past teaching methods in light of new knowledge gained through the CHEM 774 course.
- Many teachers used the Teaching Script to prepare a lesson for use in their classrooms that would positively impact student learning.

Codebook 4

Codebook 4 then allowed me to break down the teacher statements by source of motivation. Each comment was assessed to determine the focus of the comment, either focused on the participant's learning, their students' learning, or the participant's teaching. Coding frequencies are displayed in Table 196.

Table 196. Module Survey Coding Frequencies for Semester 3 Teaching Script – CB4

Code	**Abbreviation**	**Total Number of Teachers Represented (*N* = 20)**	**Percentage of Total Responses (%)**
Learning-focused	L-f	14	70
Student-focused	S-f	16	80
Teaching-focused	T-f	20	100

All participants shared teaching-focused motivations in their responses to the Teaching Script module survey. Most participants also shared student-focused (80%) and learning-focused (70%) comments as well. Some examples for statements related to teaching are given below.

- “When I teach, I try to use many visuals, models and tools that to translate it into a script is just difficult.” – Teacher 42
- “I really like to use guided inquiry activities with students prior to direct instruction. This module will change the way I present this topic to my AP Chem class in the spring.” – Teacher 22
- The course content “it has made me more cognizant of what I plan on saying and the types of questions that I ask students during the course of teaching.” – Teacher 41

The next most frequent motivation highlighted in participant responses focused on their own students. A selection of responses is given below.

- “I wanted to challenge my students with new material, but I didn't want to overwhelm them. I had to consider how to include the important stuff but keep it straightforward and simple enough that most students wouldn't struggle too much with it.” – Teacher 25
- “I now realize that the only way that students will be able to grasp the topic is to actually see and do practice have prepared blank orbital diagrams for them so that they can see the relative energies of the various sublevels and form a strong connection with the concept.” – Teacher 38

- "I have better ideas on how I can incorporate real-world examples. Examples that would be relevant to my students and their learning. I believe by relating it to my students, I would be able to get them to buy into their learning and hopefully instill some intrinsic motivation." – Teacher 11

A majority of participants also shared comments focused on their own learning. Some examples of teacher statements are given below.

- "I didn't have a good understanding of electrochemistry prior to taking this course." – Teacher 37
- "The content of this course has expanded my understanding of electrochemistry vocabulary, modeling conventions, and calculations related to electrochemistry." – Teacher 9
- The course content "has made me more confident in my overall understanding of electrochemistry and its importance within a larger scheme of chemical concepts." – Teacher 36

<u>Summary of Module Survey – Teaching Script</u>

The Teaching Script module survey allowed participants to share their thoughts on their experience creating a Teaching Script for a CHEM 774 topic. All participants shared comments focused on teaching motivations. Most participants also discussed motivations focused on their own learning (70%) and their students' learning (80%). When reflecting on the module, teachers described how the CHEM 774 course and Teaching Script experience impacted their teaching and learning. The main themes from the Fall 2022 Teaching Script survey were:

- Despite its challenges, preparing a Teaching Script for an electrochemistry, kinetics, or nuclear chemistry topic caused many participants to experience increased confidence in their content knowledge and pedagogical skill. By improving and intertwining their KoSc and KoT, teachers demonstrated improvements to the quality of their overall PCK.
- By creating a Teaching Script, teachers applied new content knowledge to a teaching context and thus practiced multiple components of PCK, including KoSc, KoT, KoG, and KoCO, by preparing a new lesson. This combination of knowledge bases indicated improved PCK quality.
- Teachers were able to incorporate their knowledge of student thinking into their Teaching Scripts, thus demonstrating KoSt and highlighting their PCK.
- The Teaching Script itself allowed teachers to reflect on their current teaching and adapt their curricula and teaching methods based on knowledge and skills gained in the CHEM 774 course. This exercise aided teachers' development of higher quality PCK.

End-of-Semester Survey

At the end of the Fall 2022 semester, I sent out an email invitation to participants of CHEM 774 and CHEM 775 to complete a survey about their experiences in core MS program courses, and the MS program overall, during the given semester. Responses to this survey were coded with Codebooks 1 and 4 (N = 18).

<u>*Codebook 1*</u>

Coding frequencies for Codebook 1 can be found in Table 197.

Table 197. End-of-Semester Survey Coding Frequencies for Semester 3 – CB1

Code	**Abbreviation**	**Total Number of Teachers Represented (*N* = 18)**	**Percentage of Total Responses (%)**
Attitudes	A-c	11	61.1
Knowledge	K-p	4	22.2
	K-c	18	100
Skill	S-c	9	50
Teaching	T	17	94.4
Background	B	3	16.7
Feedback	F	18	100
Goals	G	2	11.1
Modules	M	11	61.1
Interaction	I	13	72.2
Reflection	R	13	72.2

Examples of Attitudes (A-c)

In sharing attitudes about their experience in MS program courses during the Fall 2022 semester, several teachers described increases to their confidence teaching CHEM 774 and CHEM 775 topics.

- "The problem sets make me more confident with the calculations." – Teacher 9

- “I feel confident I can teach kinetics, nuclear, and electrochemistry well now. I also have an increased level of confidence for biochemistry and redox…I have much more confidence now to help my students in these [CHEM 774] areas.” – Teacher 37
- “Learning more about [CHEM 774 topics] helped me be more confident in teaching them.” – Teacher 29
- “My chemistry content knowledge has increased, and I am so excited about it! I am much more confident especially in the basic organic chemistry and radiation… I learned a lot in both courses-really…increasing my confidence in teaching these topics.” – Teacher 36
- “I have better confidence in these topics.” – Teacher 35
- “I came away with a confidence in my capabilities in O-Chem that were nearly zero prior to this course…Adding fluency in organic and biochem topics makes me a more capable and confident teacher across the board.” – Teacher 2
- “I feel more confident in explaining the topics covered in the classes.” – Teacher 14
- “I would feel much more confident in my ability to teach in each of these subject areas.” – Teacher 38

One teacher described struggles that still exist in relation to electrochemistry and kinetics topics.

- “I gained needed exposure to electro and kinetics but still feel that I struggle in these areas.” – Teacher 4

A few teachers described positive attitudes about their general experience in the MS program courses, including reactions to the coursework.

- "I was excited that [CHEM 774] was going to include three rather separate - perhaps only slightly related, really - big ideas in chemistry, and I was not disappointed...I feel less intimidated by that content than I did by far." – Teacher 2
- "I really enjoyed the coursework." – Teacher 23
- "I am more surprised by the fact that I am able to keep up and comprehend the material as well." – Teacher 11

Two teachers discussed bringing positive attitudes and resources to their teaching.

- "I am very happy that [the Teaching Script] gives me something that I can actually use in my classroom." – Teacher 4
- "I have also brought patience and understanding [into my teaching] after experiencing being a student again myself." – Teacher 37

One teacher expressed their disappointment that their time in the MS program is nearly over.

- "I'm honestly disappointed that I'm through four semesters already and will have to end it rather soon." – Teacher 2

<u>Summary of Attitudes (A-c)</u>

When discussing their experience in the MS program during the Fall 2022 semester, most participants (61.1%) shared attitudes, with each of these teachers describing increased confidence, contentment, and enjoyment. One teacher expressed increased confidence in some of the topics but noted that some struggles persisted. The most common themes for attitudes were:

- The MS program courses allowed teachers to gain the content knowledge necessary to feel confident in understanding and teaching these topics. Most teachers described increased confidence in relation to their teaching, which demonstrates increased PCK.
- Teachers shared positive attitudes about their experience in the MS program courses, including enjoyment of the coursework and bringing back empathy and resources to their classroom.

Examples of Knowledge (K-p and K-c)

Teachers explained how their content and pedagogical knowledge had changed over the course of the Fall 2022 semester. Many participants shared that the content from CHEM 774 and/or CHEM 775 filled gaps in their knowledge by introducing new concepts or refreshing their knowledge from their undergraduate education.

- "I do think I understand so many of the key ideas from the 775 content exponentially better now than I did before the course…774 introduced me to some really deep knowledge in the kinetics topics that I hadn't thought much about, but mostly the nuclear topics were my new knowledge gain area. I had VERY little understanding of those topics, and I grew by leaps and bounds there." – Teacher 2
- "I learned new concepts and revisited some I had learned back when taking my bachelors." – Teacher 14

- "These courses were very beneficial because I was learning about information I haven't ever learned or haven't seen in a long time." – Teacher 11
- "The content is challenging and is filling in and reteaching my undergraduate education… I remembered next to nothing about kinetics and electrochemistry. I have grown my knowledge, but electrochemistry is still a work in progress." – Teacher 9
- "I learned a lot about nuclear chemistry in the class. Much of this was new to me." – Teacher 23
- "I barely brushed the surface of these topics in my undergrad classes. A lot of the information we discussed was new to me." – Teacher 31
- "It did give me more exposure to topics that I really didn't know much about. I still don't feel strong in some areas, but I think a lot of that is because of a gap coming in." – Teacher 4

All participants ($N = 18$) discussed how their chemistry content knowledge had changed during the Fall 2022 semester, with all teachers describing increased content understanding. Some examples of teacher statements are given below.

- "I feel I have a deeper grasp on Kinetics, Nuclear and electrochemistry." – Teacher 37
- "I have better understanding of kinetics and have received more strategies to teach nuclear." – Teacher 29
- "It has improved my knowledge significantly and made me realize just how little I know about the topic of chemistry." – Teacher 11

- “This semester, I was able to review an abundance of material that I have not seen since college. I also learned more about certain aspects of chemistry than I have previously been exposed.” – Teacher 22

Several teachers described gaining new instructional resources from other teachers in the MS program.

- “I have gained some great resources from the other teachers involved through the discussion forms of 774.” – Teacher 39
- “I have gained resources other teachers have shared.” – Teacher 11
- “I gained resources from my classmates to use in class.” – Teacher 14

Many teachers demonstrated higher quality PCK by discussing how they would use their new content knowledge to improve their curricula or teaching.

- “I have become a more effective teacher because I was able to increase my knowledge of chemistry and learn about how I can better present the information in my curriculum.” – Teacher 11
- “I have gained more content knowledge that I can pass on to my students.” – Teacher 22
- “I learned several things I want to incorporate when we cover nuclear topics (stories from Strange Glow, videos that were shared in the discussion forums, lab ideas that were shared in the discussion forums, etc.).” – Teacher 31
- “I was able to bring knowledge back to my classroom to go deeper in nuclear and explain more application.” – Teacher 4
- “I learned a lot of information about kinetics, nuclear, and electrochemistry that will help me explain those concepts better to my students.” – Teacher 31

- "I enjoyed both courses and learned a lot that I can take back to incorporate into my own classes." – Teacher 22

Summary of Knowledge (K-p and K-c)

All participants gave statements reflecting increased chemistry content knowledge, as well as increased pedagogical knowledge. The main themes were:

- The MS program courses gave teachers an opportunity to strengthen their prior knowledge and gain new chemistry knowledge, which filled gaps in their overall chemistry content knowledge.
- In addition to gaining knowledge of chemistry concepts, teachers also gained pedagogical knowledge through new teaching strategies and resources.
- Participants described how improvements to their content knowledge would improve their teaching or students' learning, which demonstrates higher quality PCK by combining participants' KoSc and KoT.

Teachers' comments reflected multiple PCK bases, including KoSc, KoT, KoCO, and KoR. Participants' responses to the end-of-semester survey indicate improved PCK during the Fall 2022 semester.

Examples of Skill (S-c)

Teachers discussed changes in their pedagogical skill after participating in the MS program courses. Most teachers shared skills related to applying knowledge to their teaching contexts. Some teachers reflected on skills they use to develop lessons or present content.

- "774 was well organized and I felt like I strengthened and built on skills I learned in undergraduate…I have brought the skills that helped me this semester to my classroom plans…I have a better grasp of some of the bigger pictures so I think I am a better communicator this semester as a result." – Teacher 37

- "I found myself utilizing as many resources as possible to design material." – Teacher 14
- This semester "gives me a format on how to go about changing and/or developing curriculum or how to present on a topic that I don't have the greatest comfort level in." – Teacher 38
- "I have become a more effective teacher because I was able to…learn about how I can better present the information in my curriculum." – Teacher 11

Other teachers described gaining new teaching strategies or techniques.

- "I have acquired some different techniques and ideas for teaching concepts." – Teacher 22
- "More error-based questioning. Give them a bad answer and ask them to find the mistake. It makes you think for yourself." – Teacher 43
- "I think I have been emphasizing of exams and more emphasizing of practice and mastery in small chunks of material. I have been much more amenable to 'retakes' as that is a vital part of learning." – Teacher 36

One teacher discussed developing better time management skills.

- "Time management! I have no prep time this year due to teacher shortages, so I have learned to be more efficient while juggling student and teacher life." – Teacher 29

Summary of Skill (S-c)

Half of the participants in the end-of-semester survey discussed their current skillset after participating in MS program courses. The main themes for skill were:

- Teachers were able to apply new pedagogical knowledge to their own instruction through lesson design, the use of new teaching strategies, or curricular changes. Their description of new skills revealed their KoT, KoCO, and KoR, which highlights their PCK.
- Teachers described gaining time management, communication, and assessment skills, which all impact their teaching effectiveness.

Examples of Teaching (T)

All teachers but one ($N = 17$) gave statements relating to their own teaching. Many participants discussed bringing knowledge and ideas from the MS program courses into their classrooms. A selection of responses is given below.

- "Any time I could have practice learning a concept or learn something new that I could take into my classroom, I found the item valuable. For example, reading *Strange Glow* and having discussions helped me learn and have stories to tell my students…I have added in more demos and moved to more graphing." – Teacher 37
- "Certain aspects were meaningful because it gave me ideas and insights into how I can incorporate these new topics into my curriculum. These aspects allowed me to plan how I am going to teach certain topics inside of my classes." – Teacher 11

- "I learned several stories about radiation that I plan to incorporate into my classes. I also learned several teaching ideas (through the discussions) that I plan to incorporate into my classes." – Teacher 31
- "I learned a lot that I can take back to incorporate into my own classes…Through discussion with fellow chemistry teachers, I have been able to add several ideas for activities into my arsenal of labs and activities" – Teacher 22
- "I love the demos in the lecture videos. I have tried some of them with my students." – Teacher 9
- "I learned much about nuclear chemistry and will apply some of that knowledge to my courses." – Teacher 42
- "I have more to share with kids about real world impact events." – Teacher 13

Teachers also discussed how they grew as teachers through their experience in the MS program.

- "The assignments designed to create lessons or reflect on lessons helped me grow as a teacher." – Teacher 14
- "The course will improve my instruction." – Teacher 42
- "I have become more effective because I have been able to relate my learning opportunities to the students that I am teaching." – Teacher 38
- "I have thought more about how 'unrelated' aspects of chemistry can be used in my curriculum." – Teacher 30

Participants reflected on how topics from CHEM 774 or CHEM 775 did or did not fit into their high school chemistry curricula. Some examples are given below.

- "The information from 774 would be covered throughout a typical school year for a chemistry or AP chemistry course." – Teacher 39
- "A lot of the information [from the courses] I plan on using and incorporating into my curriculum once I am teaching chemistry again." – Teacher 11
- "The only thing is I do not teach a lot of the concepts." – Teacher 14
- "I also now feel through my course work in 774 that I am more able to teach these topics at the high school level." – Teacher 38
- "I teach much of the 774 content in my own classes…In 775, I don't teach much organic chem or biochem, honestly, in my classes. I don't suppose that's too unusual in high school classes for many of us." – Teacher 2

Summary of Teaching (T)

Teachers were able to consider how they would bring new knowledge and skills from MS program courses into their instruction. The most common themes for teaching were:

- Many teachers found aspects of the MS program courses meaningful when they were applicable to their teaching. Participants were able to bring activities, knowledge, and ideas that they gained in MS program back into their classrooms. Thus, the MS program courses directly impacted participants' teaching.
- Participants stated that their learning in the program has resulted in improvements to their teaching effectiveness, which reveals that teachers are applying knowledge to their teaching contexts.

- Teachers shared that the course content may or may not fit into their current curricula; however, the MS program equipped teachers with the knowledge and skills to be able to teach CHEM 774 and CHEM 775 topics effectively.
- Participants demonstrated KoT, KoR, KoCO, and KoSc through their end-of-semester survey responses, which shows higher quality PCK.

Background (B)

Three teachers discussed how their background relates to the knowledge they have gained in the courses, as well as their MS program experience and current teaching effectiveness. Two of these teachers reflected on their undergraduate experiences with chemistry courses.

- "After 23 years of teaching and being out of college closer to 30, I feel that there was a lot of information that was long forgotten or information that I never got while in college in the first place. I struggled mightily in Biochemistry as an undergrad mainly because I lacked the discipline and focus needed to do well." – Teacher 38
- "When I was an undergrad, there were some courses that were part of my last couple of semesters that really rounded out the content of the program for me there ... as I worked through them, I really felt the whole picture sort of coming together and feeling 'whole.'" – Teacher 2

These teachers compared and contrasted their experience in the MS program with their undergraduate education. Teacher 38 shared that they "developed that discipline to finally understand on comprehend the topics covered in 775," which contrasts with their undergraduate experience, whereas Teacher 2 felt that the MS program mimicked their positive experience in their undergraduate education by creating "the complete picture of chemistry for [them] in this [MS] program."

The third teacher mentioned that because they "have been on maternity leave" they were unable to discuss any changes to their teaching effectiveness resulting from their Fall 2022 experience in the MS program.

<u>Feedback (F)</u>

All eighteen participants shared feedback in the Fall 2022 end-of-semester survey. Data coded as feedback was sent directly to MS program instructors.

<u>Goals (G)</u>

Two teachers discussed professional goals they have for themselves related to their experience in the program. The first teacher talked about the MS program course allowing them to make progress toward their goal of recertification.

- "I enjoyed the course, and I will use the credits towards recertification." – Teacher 42

The second teacher discussed a goal to create an elective course based on CHEM 775 content that is not currently involved in their existing curriculum.

- "From the very earliest parts of the class in September and into the rest of the course, I began to imagine a semester elective course in organic chemistry that I could create in my district based on the content from this class in order to help support those students of mine in AP Chem, in particular, who might be going on to college and starting in an O-Chem class right away, where they often get shocked by the unfamiliar content. If I get a course like that up and running for our best kids to have a leg up in college, it will be worth every dollar." – Teacher 2

The MS program allowed these teachers both to fulfill existing goals and create new goals for themselves.

Examples of Modules (M)

In the end-of-semester survey, some teachers discussed their experience with the CoRe and Teaching Script modules in each of the content courses. Many teachers found the modules meaningful because they provided opportunities to practice new content knowledge and apply this knowledge to a teaching context.

- "The Teaching Script [discussion forums] brought things together very effectively and supported my personal needs in trying to really learn this diverse material." – Teacher 2
- "The Teaching Script was an interesting assignment that made me think of the content as a teacher and a learner." – Teacher 39
- "The Teaching Script helped me create a new lesson that I can use." – Teacher 29
- "The Teaching Script forces me to think about how I am going to teach these concepts in my own class and come up with the strategies I am going to implement. I like that my lessons are basically ready to go when I get to that topic in my own classes." – Teacher 11
- "I enjoyed the CoRe assignment in 775, because I was able to create a lesson that covered material that I previously thought would not really be taught at the high school level." – Teacher 22
- "The CoRe…allowed for the deeper thinking of the content." – Teacher 36

- “The [Teaching] Script is probably the most relevant to me as a teacher. I am very happy that this gives me something that I can actually use in my classroom.” – Teacher 4

Other teachers did not find the Teaching Script or CoRe meaningful, particularly because they did not find them to be practically useful.

- “The Teaching Scripts are something that I would never use as a teacher. I'd never use a script of any kind.” – Teacher 23
- “I’m also looking for better content knowledge not necessarily pedagogy for the Teaching Script.” – Teacher 35
- “The least meaningful (not saying they didn't have any meaning) were the Teaching Script in 775 and the CoRe in 774. After teaching for 23 years, I feel that I do know what it takes to teach a topic that I may feel my students or myself would struggle with. What these assignments did do for me was to formulate a thought process that I can use in the future to help with such difficulties when they should occur.” – Teacher 38

One teacher, who found the modules meaningful, stated that the modules exceeded their expectations because they would be able to use their work in the classroom.

- “I enjoyed the CoRe and Teaching Script, because those assignments gave me something to take back to my own students.” – Teacher 22

One teacher, who stated that the modules were not meaningful, felt that the assignment should be replaced.

- “Just replace the…Teaching Script assignment with something more relevant.” – Teacher 23

Finally, one teacher discussed that their pedagogical skill was transformed by their experience with the modules.

- "My pedagogical skills have been enhanced as well through my CoRe and Teaching Script assignments. They make me think about every single detail of a lesson, which makes me think about and reevaluate the rest of my curriculum before taking these classes this semester." – Teacher 11

Summary of Modules (M)

Through the end-of-semester survey, teachers reflected on their experience creating a CoRe and Teaching Script for challenging chemistry topics. The main theme for the modules was:

- For teachers who had goals for the MS program oriented with pedagogical growth, the CoRe and Teaching Script modules allowed them to reflect on the content and prepare activities that could be used in their classrooms. Other teachers did not find value in the modules because they did not think the assignments had a practical use.

Examples of Interaction (I)

Through interactions during the MS program, participants described learning and gaining resources from fellow teachers.

- "As a teacher I valued discussion forums and teaching script we had in Chem 774 because it helped me see what other teachers think about topics we went over and how they implement these topics in their teaching." – Teacher 29
- "The forums where a good way to learn from others." – Teacher 23

- "I have gained some great resources from the other teachers involved through the discussion forms of 774." – Teacher 39
- "I'm trying new techniques and content based on suggestions by other teachers." – Teacher 9
- "I have gained resources other teachers have shared. In addition, I have gained wisdom through my peers' experiences, as they have been teaching a lot longer than me." – Teacher 11
- "I gained resources from my classmates to use in class." – Teacher 14
- "Through discussion with fellow chemistry teachers, I have been able to add several ideas for activities into my arsenal of labs and activities." – Teacher 22

In addition to gaining resources, participants have also formed a sense of community by interacting with a geographically diverse group of science teachers.

- "I love how we have bonded as classmates. The study groups helped me feel more confident and now connected to teachers all over the country. It is great to have a group to run ideas by or help out when needed." – Teacher 37
- "Connections with other teachers around the world. Professors that care about their students and are willing to answer any questions we throw at them." – Teacher 31
- "Meeting weekly with teachers around the country is very valuable." – Teacher 9
- "Lots of professional connections with my peers." – Teacher 23
- "Meeting other teachers is always great and helps to give perspective." – Teacher 4
- "A community." – Teacher 30

Summary of Interaction (I)

Participants found value in interactions they had with other teachers in the MS program. The most common themes for interactions were:

- Participants were able to learn in community with one another through the MS program. Teachers from around the country exchanged ideas and resources, which allowed for greater pedagogical growth by gaining new perspectives. These interactions emphasized teachers' KoR, a component of PCK.

The MS program provided a unique opportunity for science teachers to continue their work in the classroom while gaining chemistry content knowledge. The network created by MS program participants highlighted the importance of these interactions for teachers' professional growth.

Examples of Reflection (R)

The end-of-semester survey allowed teachers to reflect on their overall experience in the MS program during the Fall 2022 semester. Most teachers (*N* = 13, 72.2%) provided reflective comments. Some participants reflected on their learning in MS program courses, including learning preferences.

- "As a learner, having solutions for homework sets and exams helped me reflect on mistakes I made." – Teacher 29
- "I learn better by watching and listening to a lecture, rather than just reading." – Teacher 22
- "The content for 774 is so widely varied in topics that it kept me incredibly on my toes." – Teacher 2

Teachers also reflected on the purpose of their learning, including preparing themselves for improved teaching.

- "When the students ask questions, I never like having to say I will need to look that up. I do, but I would prefer knowing." – Teacher 43
- "The more information I am able to obtain, the better prepared I will be for my students. It was interesting learning and listening alongside other teachers who have been teaching for a lot longer than I have. It showed me that I must always be a lifetime learner and I have a lot way to go before I truly understand most of these chemistry concepts and topics." – Teacher 11
- "I think that with any time a teacher has to act as a student, we are remiss if we don't want to change our pedagogical approaches!" – Teacher 36

Some teachers described the impact the MS program has had on their interactions with students.

- "If anything, perhaps it gives each of us more of an appreciation for what each of us do as far as a learner and a teacher." – Teacher 38
- "Having my students know I also have homework besides grading their stuff has made them a little more patient with my grading." – Teacher 43

Teachers also described how the MS program courses prompted them to reflect on their teaching practices.

- "I have thought more about how 'unrelated' aspects of chemistry can be used in my curriculum." – Teacher 30
- "I have thought about changes that I want to make to my lessons when we cover some of these topics." – Teacher 31

- "I have realized where my limitations are and can now begin to make a plan on how to overcome those limitations for my students." – Teacher 11

The remaining teacher statements focused on general reflection on participants' experience in the MS program and its impact on their learning and teaching. A selection of responses is given below.

- "It was interesting to see the depth of the work as even an AP curriculum really just touches the base of the topics." – Teacher 42
- "I struggled mightily in Biochemistry and an undergrad mainly because I lacked the discipline and focus needed to do well. Now that I am older, I feel like I developed that discipline to finally understand on comprehend the topics covered in 775." – Teacher 38
- "I have been a Biology teacher first for years, but I feel myself becoming a Chemistry teacher first." – Teacher 9
- "I have to always remember to slow down and start at the very beginning to build an appropriate foundation." – Teacher 36

<u>Summary of Reflection (R)</u>

Through the end-of-semester survey, participants reflected on how their experience in the MS program has impacted them as learners and teachers. The main themes for reflection were:

- Teachers expressed their learning preferences and reflected on connections between their learning and the content they teach in their classrooms. These comments reflect KoT and KoCO, which reveal teachers' PCK.

- Participants discussed the purpose of pursuing the MS degree, which emphasized the importance of improving their teaching effectiveness through improved content and pedagogical knowledge. Again, these statements showcased teachers' PCK through their KoT and KoG.
- Teachers became students again through the MS program, which allowed them to gain better empathy for their students' learning experience. Similarly, their own students expressed understanding and appreciation for their teachers' time spent working toward their MS degree.

Teachers reflected on their experience in the MS program, particularly related to knowledge and skills gained that they could apply to their own teaching.

Codebook 4

Codebook 4 was used to analyze participants' motivations for statements made in the end-of-semester survey. Coding frequencies can be found in Table 198.

Table 198. End-of-Semester Survey Coding Frequencies for Semester 3 – CB4

Code	**Abbreviation**	**Total Number of Teachers Represented (*N* = 18)**	**Percentage of Total Responses (%)**
Learning-focused	L-f	18	100
Student-focused	S-f	11	61.1

Teaching-focused	T-f	18	100

All participants shared teaching-focused and learning-focused motivations in their responses to the end-of-semester survey. Many participants also shared student-focused (61.1%) comments. Some examples of learning-focused comments are given below.

- "These courses were very beneficial because I was learning about information I haven't ever learned or haven't seen in a long time." – Teacher 11
- "I learned a lot about nuclear chemistry in the class. Much of this was new to me." – Teacher 23
- "This semester, I was able to review an abundance of material that I have not seen since college. I also learned more about certain aspects of chemistry than I have previously been exposed." – Teacher 22

All eighteen participants gave comments motivated by their teaching. A selection of responses is given below.

- "I am now better equipped to teach this to all sections of chemistry and have the know-how to answer most questions that students may have." – Teacher 38
- "As a teacher I valued discussion forums and teaching script we had in Chem 774 because it helped me see what other teachers think about topics we went over and how they implement these topics in their teaching. The teaching script helped me create a new lesson that I can use." – Teacher 29
- "I learned several things I want to incorporate when we cover nuclear topics (stories from Strange Glow, videos that were shared in the discussion forums, lab ideas that were shared in the discussion forums, etc.)." – Teacher 31

Many teachers (*N* = 11, 61.1%) discussed their experience in the MS program in terms of the impact it has had or may have on their own students. Some examples of teacher statements are given below.

- "The Strange Glow book has also been great, and I have shared stories with my students that really captivated their attention." – Teacher 4
- "The more information I am able to obtain, the better prepared I will be for my students." – Teacher 11
- "I began to imagine a semester elective course in organic chemistry that I could create in my district based on the content from this class in order to help support those students of mine in AP Chem, in particular, who might be going on to college and starting in an O-Chem class right away, where they often get shocked by the unfamiliar content." – Teacher 2

<u>Summary of End-of-Semester Survey</u>

Eighteen participants completed the end-of-semester survey and shared their thoughts on CHEM 774, CHEM 775, and the MS program as a whole during the Fall 2022 semester. All participants shared statements motivated by their own teaching and learning, while a majority (61.1%) also discussed student-focused motivations. The most common themes from the end-of-semester survey were:

- The content knowledge that teachers developed through MS program courses led to improved teaching confidence. Increased KoSc, KoT, and KoR led to increased PCK.
- The MS program courses filled gaps in participants' content understanding (KoSc), which allowed them to improve their own students' learning through

improved PCK. This combination of KoSc and KoT would lead to improved PCK quality.

- Teachers experienced improved teaching effectiveness through their development of new pedagogical knowledge (KoCO, KoT, and KoR), including knowledge of lesson design, teaching strategies, and activities. This combination of knowledge bases demonstrates higher quality PCK. Improvements to their KoR through interactions with other high school science teachers led to improved PCK.
- Participants' goals for the MS program aligned with their teaching. Teachers derived meaning from course assignments that allowed them to develop resources to use in their own classrooms. Similarly, teachers found value in gaining knowledge and skills that would impact their own teaching. The MS program enabled teachers to develop PCK and experience professional development.

Summary of Semester 3

During Semester 3 of data collection, methods included the pre-chemistry content survey, the CoRe module and its survey, the Teaching Script module and its survey, and the end-of-semester survey. The main themes for Semester 3 were:

- As evidenced by the pre-chemistry content survey, some participants entering MS program courses have low comfort levels and confidence with the content, demonstrating that growth in teachers' chemistry content knowledge (KoSc) is possible and necessary for professional development. The MS program content courses support teachers' development of KoSc as a component of their PCK.
- Through the CoRe and Teaching Script modules, teachers demonstrated their PCK related to kinetics, electrochemistry, nuclear chemistry, organic chemistry,

and biochemistry. By completing the modules, teachers revealed the presence and quality of their PCK. By combining PCK bases and reflecting on their teaching decisions, teachers demonstrated higher quality PCK. In the Teaching Script, fewer teachers demonstrated KoA, which may indicate a potential gap in their PCK.

- Through the modules, teachers reflected on their current instruction of CHEM 774 and CHEM 775 topics and discussed how they could bring these topics into their teaching, demonstrating KoSc, KoG, KoCO, and KoT as components of their PCK. The MS program courses filled gaps in teachers' KoSc and enabled participants to increase their confidence teaching these topics. By combining their KoSc and KoT, teachers demonstrated improvements to the quality of their overall PCK through the MS program content courses.
- Teachers gained KoR through their interactions with other MS program participants, which led to improved PCK. Participants also increased their teaching effectiveness through their development of new KoSc and KoT, which also indicated improvements to the quality of their overall PCK.
- Teachers applied knowledge and skills from the MS program to their teaching, which demonstrated the MS program's direct impact on participants' instruction. This application of knowledge also indicates improvements to the quality of teachers' overall PCK. Participants also developed resources to use in their own classrooms. The MS program impacted participants' learning and teaching, which may then have impacted the participants' students' learning.

Semester 4

During Semester 4, teachers were able to participate in one content course. CHEM 773 focused on equilibria and acid-base chemistry topics. This course was fully online and primarily asynchronous. Optional weekly Zoom sessions were the only synchronous components of the course. The data for Semester 4 is presented chronologically. Discussion forums from CHEM 773 were used to gain a better understanding of how the course content impacted participants' content and pedagogical knowledge. Questions were prompted to the discussion forum near the end of the semester. The CoRe assignment was due at the end of the semester, along with the CoRe module survey. The End-of-Semester survey was sent out after the conclusion of the semester. Table 199 discusses the methods used during Semester 4.

Table 199. Semester 4 Data Collection Methods

Term	**Data Collection Methods**	**ID Codes**
Semester 4	**CHEM 773:**	
	Discussion Forums	DF
	CoRe	CoRe
	Module Survey	MS
	General:	
	Chemistry Content Survey (post-test)	CCS
	End-of-Semester Survey	EOS

Discussion Forums (CHEM 773)

In the Spring 2023 semester, discussion forum threads were introduced into the CHEM 773 course once near the end of the semester to learn more about how this content course impacted participants. The discussion forum questions related to the impact of the course on the teaching of specific chemistry topics, what changes participants carried out (or planned to carry out) in their classrooms, and what new knowledge the teachers took away from the discussion forums in general. The narrative participant did not respond to any of these discussion forum threads, so Semester 4 discussion forum data is only available for the general MS program population. Specific questions can be found in Appendix J. Discussion forums were analyzed with Codebooks 1 and 4.

Codebook 1

Codebook 1 provides general coding for the dataset. The codes and frequency of teacher responses can be found in Table 200.

Table 200. Discussion Forum Coding Frequencies for Semester 4 – CB1

Code	**Abbreviation**	**Total Number of Teachers Represented (*N* = 20)**	**Percentage of Total Responses (%)**
Attitudes	A-p	2	10
	A-c	5	25
Knowledge	K-p	1	5
	K-c	11	55

Skill	S-p	1	5
Teaching	T	19	95
Experience	E	1	5
Feedback	F	1	5
Modules	M	2	10
Background	B	5	25
Interaction	I	14	70
Reflection	R	17	85

Examples of Attitudes (A-p and A-c)

Five of the teachers shared comments related to their attitudes, with two commenting on prior attitudes and all five revealing their current attitudes. One teacher discussed their hesitation to include titrations in their chemistry course prior to taking CHEM 773 but described a shift in their attitudes due to their experience in the course.

- "I was hesitant to do titrations with my regular chemistry students, but after talking about different ways to teach it through discussion forums conversations and also using it as the topic for CoRe assignment (hence having a good lesson plan ready to use), I think I will give it a try." – Teacher 29

Many of the teachers' comments coded as attitudes related to their confidence both understanding and teaching chemistry concepts. One teacher discussed both their prior and current confidence levels after participating in the CHEM 773 course.

- "I did not have the confidence to teach this topic well enough to do it justice…This course has now given me the confidence…to cover this topic in class without hesitation." – Teacher 38

Three other teachers also described positive shifts in their confidence teaching and understanding equilibria topics.

- "I think I'm more confident in describing simple explanations of equilibrium without feeling like I'm guessing." – Teacher 25
- "I am much more confident in my own understanding of the content." – Teacher 41
- "The course, so far, has given me the…confidence to build in the various topics related to equilibria into my curriculum." – Teacher 11

Summary of Attitudes (A-p and A-c)

A quarter of the teachers ($N = 5$) shared comments about their attitudes toward teaching and learning chemistry. The main themes for attitudes were:

- Teachers gained confidence in their teaching and understanding of chemistry concepts after taking the CHEM 773 course.
- One teacher described hesitation to include titration lab activities in their teaching of a general chemistry course, but their experience in the CHEM 773 course gave them a willingness to try.

Examples of Knowledge (K-p and K-c)

One teacher shared that, by gaining more knowledge in the MS program, they will be able to teach AP Chemistry concepts in greater depth than they had in the past.

- "I feel as though I have more information to draw from regarding practice problems, demonstrations, general explanations, and even tougher examples for students to practice. I feel as though I can go beyond the AP Chemistry curriculum requirements whereas before I was teaching to the AP Chem curriculum." – Teacher 41

Many teachers discussed gaining new chemistry content knowledge through CHEM 773. Some described specific chemistry knowledge they gained.

- "I have a better understanding of weak acids and buffered solutions." – Teacher 4
- "This course has expanded my knowledge of the many aspects of equilibria." – Teacher 39

Others mentioned gaining new information that would help them teach the topics more effectively, including new content knowledge, teaching strategies, or activities. By connecting their KoSc, KoT, and KoR, teachers demonstrated improvements to their PCK.

- "I have new ideas to use for demos and real-world examples." – Teacher 22
- "I have picked up my new knowledge and new ideas; demos, teaching strategies, and activities that I have already incorporated into my instruction." – Teacher 42
- "This course has now given me…the knowledge to cover this topic in class without hesitation." – Teacher 38
- "I also have more information to provide for those who are extra curious." – Teacher 25
- "This course has given me many ideas for how I can incorporate equilibria topics in the future. I have been able to gather a variety of different demonstrations, labs,

and teaching strategies. Ultimately, the course, so far, has given me the knowledge…to build in the various topics related to equilibria into my curriculum." – Teacher 11

In one discussion forum thread, teachers were asked what they had taken away from the course discussion forums. Of the eight teachers who shared knowledge changes, six discussed gaining new resources in the form of activities, demonstrations/labs, or teaching strategies. Again, this combines teachers' KoT and KoR, which demonstrates PCK.

- "The biggest things I've taken away from these discussions have been ideas for demos." – Teacher 45
- "I also have taken ideas for demos or labs from the discussion portion of this class." – Teacher 44
- "Demonstrations and labs are always a big take away from discussions." – Teacher 4
- "There have been many great activities and strategies mentioned that I would like to try throughout the course of AP Chemistry next year." – Teacher 41
- "I have also gotten some ideas for class activities." – Teacher 22
- "I have always found the discussion posts to be a place of collaboration and a wealth of knowledge and resources…I have been able to learn about demonstrations for various topics and teaching strategies that work well for the different topics we've covered in class." – Teacher 11

Three participants also shared gaining knowledge of equilibria examples from fellow teachers. By connecting their KoSc to their KoT, they revealed improved PCK.

- “One thing I have taken is examples of equilibrium we have discussed.” – Teacher 14
- “The discussions of people’s papers were also interesting with examples I could incorporate.” – Teacher 4
- “There is so much knowledge and experience that is conveyed through the discussions I have found them very useful.” – Teacher 42

<u>Summary of Knowledge (K-p and K-c)</u>

Over half of the teachers (55%) shared content and pedagogical knowledge they had gained through the CHEM 773 course. The most common themes for knowledge were:

- Learning equilibria topics in CHEM 773 allowed participants to increase their chemistry content knowledge (KoSc). Participants discussed applying their new knowledge to their teaching (KoT), which demonstrates increased PCK.
- Through the discussion forums, teachers exchanged activities, teaching strategies, and examples of the content that could be used during instruction. This increased participants’ KoR and KoT, which positively impacted their overall PCK.

<u>Skill (S-p)</u>

One teacher discussed their skill level prior to the CHEM 773 course, stating that they did not teach equilibria topics because they were “not prepared to answer questions that [they] would anticipate from the students” (Teacher 38). This comment reveals this teacher’s baseline for pedagogical skill prior to gaining new content knowledge in CHEM 773.

Examples of Teaching (T)

All teachers but one (*N* = 19) discussed how the CHEM 773 course has impacted their teaching. Many participants discussed their plans for incorporating new activities or teaching equilibria in greater depth. Some examples are given below.

- "I also plan to use more particle diagrams and inquiry type activities next year." – Teacher 22
- "I feel more prepared to cover them in greater depth at the conceptual level with my current classes but and also with calculations if I am able to teach college credit next year." – Teacher 4
- "Using RICE tables and new initials was extremely beneficial to myself and my students. I found it was most helpful for organizing an approach to solving buffer problems." – Teacher 37
- "I have found myself now using demo ideas and using more drawings similar to that of Instructor A when they draw their beakers with ions in them when discussing single and double replacement reactions to my students." – Teacher 38

Some teachers discussed not altering the current content they teach as a result of the course. However, the course impacted their confidence, which brings in statements also coded as A-c.

- "For the level of chemistry that I teach, [the course] hasn't changed the material that I cover when I talk about equilibrium. However, I think I'm more confident in describing simple explanations of equilibrium without feeling like I'm guessing." – Teacher 25

- "It has not really changed my teaching much this semester either." – Teacher 5
- "I am still teaching the same material, however, I am much more confident in my own understanding of the content." – Teacher 41

Teachers also stated that they gained ideas for their future teaching in the discussion forums. Many of these ideas came from fellow teachers' posts.

- A fellow teacher "posted about using a saturated NaCl solution and adding HCl for a common ion/Le Châtelier's principle demo. They also posted a fantastic explanation for determining strength of acids which I have screen shot for reference in the future when I am teaching AP again next year." – Teacher 45
- "One thing I have taken is examples of equilibrium we have discussed. There were a bunch of great examples I have used in a class discussion about examples and the relevancy of equilibrium in the real world." – Teacher 14
- "Being able to read the equilibrium discussions has been really helpful to me because this is the first year we have a bit more time to dive deeper into the topic so being able to give a lot of real world examples helps make our chem class more relatable and enjoyable." – Teacher 9
- "There have been many great activities and strategies mentioned that I would like to try throughout the course of AP Chemistry next year. I can recall several different links that [three other teachers] have posted and interesting sites that they referenced that I have bookmarked. There were also a lot of labs and demos for Le Châtelier's Principle that would make great attention getters for lessons or mini-labs/stations for students." – Teacher 41

- "There are many different ideas that I plan to try and incorporate into my teaching next time I have a chemistry class." – Teacher 11

Participants were then asked to describe any teaching changes they made due to what they learned in CHEM 773. Some teachers described new strategies they brought into their classes, with particle diagrams and graphing being commonly mentioned.

- "I tried a particle diagram type activity when teaching titration curves. We drew and labeled the species present at each important part of the curve and talked about how to calculate pH. I think it helped." – Teacher 22
- "I changed my titration lab to include graphing and particle diagrams. I've also worked with one student who struggles with math doing ice tables which is not something I normally do." – Teacher 4
- "I included graphing and particle diagrams for teaching titrations and buffers. This helped students significantly. I attached one of my student's work to demonstrate what they understood and accomplished. I also included a more comprehensive discussion of Q vs K after spending time with this concept in this class. It seems to be helping students make more predictions." – Teacher 37
- "I have been trying to incorporate more particle level diagrams into my teaching so that students have a visual representing what is happening to the atoms/ions/molecules/ etc. during the process being discussed. It really helped during the limiting / excess reactant discussion (especially during pressure calculations with gases). It has also helped during titration curves and buffer discussions. I have also stressed during equilibrium calculations that Q is during ANY time while K is only at equilibrium. I tried a new initials approach with

them so they could see that it doesn't matter what the (Q) initial values were, K will be the same values. That really seemed to make a difference for some struggling students." – Teacher 41

- "I think the only change for this year is going to be to include graphing with my titration lab." – Teacher 45

In addition to particle diagrams and graphing, teachers also discussed including the ICE method and writing assignments.

- "I'm going to keep using the ICE table method for stoich[iometry], and next year when I teach college chemistry I am definitely using them because I know students will need them in the future." – Teacher 46
- "Another topic I plan on including in the future is equilibrium, and to do an assignment like our stories we have to write [in CHEM 773]. I would like the students to find an example they could present to the rest of the class." – Teacher 11

One teacher discussed broader changes to their teaching philosophy by adjusting due dates and allowing for retakes on assessments. This teacher demonstrated their KoG and KoA as components of PCK.

- "I have tried to have some 'rolling' deadlines for assignments in my AP classes. There is always more material to go over so tests will get done when they get done but we need to keep going through the material. In my honors classes I am also trying to stress both conceptual and calculations in chemistry. I have been using the LMS from my school to create tests which allow students to retake and yet also change a value in the equation." – Teacher 9

Summary of Teaching (T)

In these discussion forum threads, teachers reflected on how the CHEM 773 course introduced them to new teaching ideas or led them to make instructional changes in their own classrooms. The main themes for teaching were:

- MS program participants exchanged teaching strategies and activities with each other, which highlights the value of interactions in the program.
- Gaining new content knowledge impacted participants' teaching confidence. Although teachers may not have altered their instruction in real time during the Fall 2022 semester, many teachers posted ideas for future teaching changes to the discussion forum. These changes included new ideas for demonstrations, lab activities, or teaching methods. Teachers gained PCK by increasing their KoT and KoSc.
- Teachers were able to discuss changes they made to their teaching and evaluated the impact of these changes on student learning. Multiple teachers shared that new teaching strategies learned in CHEM 773 helped their students.

Experience (E)

One teacher discussed their experience developing their action research project for the MS program. This teacher described the intended purpose of their project and the process of choosing a topic of focus.

- "I am working on my action research project for next year and part of that is incorporating more inquiry. I am still not sure how it will look, but I do know that the one I am thinking about doing is probably not going to deal with equilibrium." – Teacher 5

By sharing details about their experience in the program, Teacher 5 reveals the reflection involved with choosing and carrying out an action research project as part of the MS program requirements.

Feedback (F)

One participant shared feedback in the Spring 2023 discussion forum. Data coded as feedback was sent directly to MS program instructors.

Modules (M)

Two teachers discussed the CoRe module as a component of the CHEM 773 course. Both teachers shared that the CoRe assignment allowed them to prepare for teaching their chosen topic.

- "I was hesitant to do titrations with my regular chemistry students, but after…using it as the topic for CoRe assignment (hence having a good lesson plan ready to use), I think I will give it a try." – Teacher 29
- "Something I plan on incorporating in the future is Acid/Base Titrations, and I'll have a good start on that because that is what my CoRe Assignment is going to be over." – Teacher 11

Through these comments, both participants demonstrated that they would apply knowledge gained from the MS program to their teaching.

Examples of Background (B)

Five teachers shared details about their background, including information about their teaching contexts. Three teachers discussed the science courses they currently teach.

- "I do not teach equilibria in the courses I currently teach…I teach physical science. This semester is our physics semester…I am not a chemistry teacher but would like to be someday." – Teacher 39
- "I haven't taught equilibria topics before, so I don't have a lot of experience…Currently, I am not teaching any chemistry classes and the only time it came up was for one chapter in 8th grade science." – Teacher 11
- "I only teach general chemistry." – Teacher 46

One teacher shared that they are the only chemistry teacher at their school.

- "Being the only chemistry teacher in my high school I have no one to bounce ideas off of." – Teacher 42

The final teacher comment related to background touched on a teacher's reasons for not being about to teach equilibria topics in depth.

- "Aside from acid-base equilibrium, [equilibrium] is a topic that I have not been generally been able to teach due to our school schedule and lack of time to cover this topic." – Teacher 38

By sharing details about their teaching contexts, teachers could explain their inclusion or exclusion of certain CHEM 773 concepts in their curricula.

<u>Examples of Interaction (I)</u>

Most teachers (*N* = 14, 70%) discussed the value of interactions they have had in the MS program, or demonstrated these interactions by responding to each other's posts to the discussion forums. Six participants interacted with fellow teachers on the discussion forums by expressing agreement. Five teachers showed interactions by saying they would like to use a peer's ideas in the future. A few examples are given below.

- “[Teacher] has many great ideas! I do not if it is something to do with them teaching AP for some time or they are just a great teacher, but every time they post any activities or demos, I want to use them in my class.” – Teacher 29
- “I could add a demonstration that introduces a common ion like [teacher] mentioned.” – Teacher 9
- “I can't remember who, but someone here convinced me to hand graph a titration to really achieve a lightbulb moment as the equivalence and endpoints are reached.” – Teacher 45

Several teachers enjoyed getting ideas from fellow science teachers, with some also expressing the value of these interactions.

- “I have enjoyed working on the equilibrium paper and seeing everyone's ideas.” – Teacher 22
- “I've also enjoyed reading everyone's blurbs about their equilibrium topic…It's also interesting to see the variety of different concerns based on where everyone is at.” – Teacher 25
- “There is no substitution for the collective experiences of the group and hearing how different teachers tackle topics in different ways is very informative.” – Teacher 42
- “I enjoy reading what other teachers do in their classrooms…I find this wealth of knowledge valuable and really enjoy when teachers share demos, websites, labs etc.” – Teacher 39

- "Being the only chemistry teacher in my high school I have no one to bounce ideas off of so it has been nice to touch base with other chemistry teachers." – Teacher 42
- "I have always found the discussion posts to be a place of collaboration and a wealth of knowledge and resources. I have enjoyed reading and learning from all of the other teachers through the discussion forums." – Teacher 11

One teacher described their interest in becoming an AP reader, which they believe would allow them to have meaningful interactions with other teachers.

- "I think one of the interesting potential side benefits of being an AP reader in the future would be to see the various ways that students effectively approach solving different problems and getting that glimpse into what other teachers are using as their teaching methods on these things. I had always thought most of the chance to visit with other teachers in person, but 'collaborating' with teachers through the work of their students seems to be a great possibility." – Teacher 2

<u>Summary of Interaction (I)</u>

Teachers both exhibited interactions through the discussion forum threads or described the value of interacting with fellow science teachers through the MS program. The main theme for interactions was:

- Teachers gained examples and teaching resources from their fellow MS program participants. These interactions were meaningful for teachers and many highlighted the value of collaborating with other science teachers.

Examples of Reflection (R)

In addition to sharing knowledge and resources they had gained through the CHEM 773 discussion forums, most teachers (*N* = 17) reflected on the impact that the MS program has had on their teaching and learning. A selection of teacher statements is given below.

- “It's good to have an arsenal of different examples of equilibrium in real life, because many of the examples that I've been using don't exactly apply to the students.” – Teacher 25
- “I also found it interesting certain topics that I teach my students have been dropped from AP vs what is taught in AP that I am not covering. I wonder if it would be beneficial to make some of these same changes with my regular chemistry classes maybe not to the same depth but just to get a taste of different topics.” – Teacher 4
- “I think it's important that [students] can learn from their mistakes and yet also show mastery of the chemistry content.” – Teacher 9
- “I think key phrases and ideas like that sometimes allow the students to breathe a sigh of relief as the ‘why’ or ‘justify’ becomes that much more accessible.” – Teacher 36

Summary of Reflection (R)

In the discussion forums, teachers reflected on their experience in the CHEM 773 course and how it relates to their current or future teaching. The main themes for reflection were:

- Teachers made connections between the CHEM 773 course content and their own teaching, demonstrating their KoT and KoCO and overall PCK.
- By reflecting on their discussion forum comments, teachers revealed their teaching philosophies and intentions for student learning through the topics and strategies they planned to implement in their classrooms.

Codebook 4

Codebook 4 was used to categorize the motivations behind the participants' comments in the discussion forums. Coding frequencies can be found in Table 201.

Table 201. Discussion Forum Coding Frequencies for Semester 4 – CB4

Code	**Abbreviation**	**Total Number of Teachers Represented (*N* = 20)**	**Percentage of Total Responses (%)**
Learning-focused	L-f	8	40
Student-focused	S-f	9	45
Teaching-focused	T-f	20	100

All participants shared teaching-focused motivations in their posts to the discussion forums. Fewer than half of the teachers shared student-focused (45%) or learning-focused (40%) comments. Since the discussion threads primarily prompted participants to reflect on their teaching, all teachers gave teaching-focused comments. A selection of teacher statements is given below.

- "I have picked up my new knowledge and new ideas; demos, teaching strategies, and activities that I have already incorporated into my instruction." – Teacher 42
- "I tried a particle diagram type activity when teaching titration curves. We drew and labeled the species present at each important part of the curve and talked about how to calculate pH." – Teacher 22
- "I think the only change for this year is going to be to include graphing with my titration lab." – Teacher 45

Nine of the twenty teachers (45%) gave comments focused on their students' learning. Some examples are given below.

- "I think the discussions for the book topics provided good examples that are accessible to students." – Teacher 36
- "Through the discussions I am seeing multiple places where I could explore and expose my students to the concept of equilibrium and multiple places in my curriculum." – Teacher 9
- "I tried a new initials approach with them so they could see that it doesn't matter what the (Q) initial values were, K will be the same values. That really seemed to make a difference for some struggling students." – Teacher 41

Eight of the twenty teachers (40%) commented on their own learning in the MS program. A selection of teacher statements is given below.

- "I have a better understanding of weak acids and buffered solutions." – Teacher 4

- “This course has expanded my knowledge of the many aspects of equilibria.” – Teacher 39
- “There is so much knowledge and experience that is conveyed through the discussions I have found them very useful.” – Teacher 42

<u>Summary of Discussion Forums (CHEM 773)</u>

The discussion forum threads invited teachers to reflect on how the CHEM 773 course has impacted their learning and teaching. All teachers gave comments motivated by their own teaching, while just under half of participants discussed student-focused (45%) and learning-focused (40%) motivations. The main themes from the discussion forums were:

- Teachers gained confidence in teaching and understanding equilibria topics due to increases to their content knowledge. Increased KoSc, KoT, and KoR led to increased PCK for MS program participants.
- Through the discussion forums, MS program participants interacted with each other through the exchange of information and teaching resources, which increased teachers’ KoSc and KoT, thus increasing their PCK. Teachers found high value in interacting with fellow science teachers, which supported their PCK and professional development.
- Teachers reflected on how they plan to bring CHEM 773 topics into their classrooms in the future. This reflection allowed them to combine knowledge bases and improve the quality of their overall PCK.

CoRe

In Spring 2023, the CoRe was administered in CHEM 773: Equilibria & Acid-Base Chemistry. The CoRe was analyzed using Codebook 2 to assess participants' PCK. Table 202 displays the codes from Codebook 2 that appeared in the Semester 4 CoRe.

Table 202. CoRe Coding Frequencies for Semester 4 – CB2

Code	**Abbreviation**	**Total Number of Teachers Represented (*N* = 20)**	**Percentage of Total Responses (%)**
Knowledge of science	KoSc	20	100
Knowledge of goals	KoG	20	100
Knowledge of students	KoSt	20	100
Knowledge of curriculum organization	KoCO	20	100
Knowledge of teaching	KoT	20	100
Knowledge of assessment	KoA	17	85
Knowledge of resources	KoR	14	70

The CoRe assignment was created to gain information about participants' PCK, so it is not surprising that most codes were present in each of the responses. As mentioned in the literature review chapter, researchers have been encouraged to investigate the quality of PCK, not only its existence or quantity.[43] Based on the design of the CoRe, all participants should have prior PCK.

Examples of KoSc

The first component of PCK represented in the CoRe is KoSc, which includes science content, scientific practice, the nature of science, and scientific progress.[41] Teachers identified a challenging topic related to equilibria and acid-base chemistry. The most commonly chosen topics were titration curves ($N = 7$), buffers ($N = 4$), and Le Châtelier's principle ($N = 3$). The remaining teachers chose to focus their CoRe on phase diagrams ($N = 2$), equilibrium constants ($N = 2$), and general acid-base chemistry ($N = 2$).

All but three teachers described their reasoning behind their topic choices. Many teachers chose the topic due to challenges their students face. These comments will be discussed in the KoSt section. For some participants, it would be difficult to teach their chosen topic due to a lack of experience.

- "It would be difficult for me to teach because I haven't taught titrations before and really haven't had much experience with them." – Teacher 11
- "While there are hundreds if not thousands of examples of equilibrium and how stress affects it, this is the first year I will teach this to my students. Not feeling 100% confident in the material and the difficulty level for general chemistry students makes me a little apprehensive." – Teacher 44

- "Buffers are one of the most challenging topics for me to teach. First, I have only a few years of teaching AP chemistry under my belt. On top of that, I haven't taught it for the last 4 years after moving to a new school. Next year, I will finally be back in the AP Chemistry classroom… It has been years since I've taught buffers (it doesn't make the cut for our honors curriculum). I need to review and solve these problems on my own before teaching them (part of the reason I'm taking this class!)." – Teacher 45

Some teachers discussed the inherent difficulty of the content, including the knowledge and skills necessary for mastering the topic.

- "In the diagrams, there are phase changes including gas, liquid, and solid. What makes this topic difficult is how the phase diagrams will look different depending on the substance." – Teacher 14
- "Titration curves are difficult to both learn and teach because they require a fair amount of background knowledge of the subject (teach) and the application of them is pretty wide (learn)." – Teacher 36
- "Buffers require students to also know which acids and bases are weak and strong and how that affects a titration." – Teacher 41
- "Buffers is the most challenging concept for me to teach because the topic can be abstract and requires problem solving…Teaching buffers takes time, patience and practice." – Teacher 37

One teacher described their own struggle with the content and connected this to their KoSt as well. This teacher felt their own learning challenges may translate to their students' learning.

- For acid strength, “I struggled to know which trend to focus on first, like atom size, electronegativity, or number of oxygens attached to the central atom, and I’m sure students will struggle as well.” – Teacher 46

One teacher discussed the challenge of simplifying their knowledge of an advanced topic in order to fit their students’ level of understanding.

- “This topic is also difficult for me because of my advanced understanding of the concept. Sometimes it takes a lot of brain power to make sure that the terms you are using are not too advanced for your students.” – Teacher 5

Participants then discussed intended learning outcomes for students for their CoRe lesson. A selection of responses is given below.

- “Explain the relationship between the ability of a buffer to stabilize pH and the reactions that occur when an acid or a base is added to a buffered solution.” – Teacher 45
- “Students would have an objective to identify substances as acids or bases, given a description, example or a picture. And how to read the pH scale period. Students should also be able to define vocabulary words such as acids, bases, electrolytes, pH.” – Teacher 39
- “By the end of the lesson, students will be able to graph collected/provided data; recognize the relationship between the volume of titrant and pH of the solution; and identify the main points of titration and data from constructed titration curve.” – Teacher 29

After sharing intended learning outcomes, teachers explained what additional knowledge they have on their topic beyond what they would teach to students. Some examples of teacher statements are given below.

- “Le Châtelier’s principle can also be used for changes in volume/pressure of a gas and has to deal with the number of moles. Since I want students to have some idea about equilibrium, but not in-depth knowledge, I am fine excluding volume/pressure from my lesson.” – Teacher 25
- “How to describe equilibrium systems mathematically, calculating equilibrium constants (Q and K) and apply them.” – Teacher 44
- “By altering the concentrations of the acid-base pairs one can sort of “dial in” a very specific pH of a buffer system. By using the Henderson-Hasselbalch equation: $pH = pK_a + \log [Base]/[Acid]$ or $pOH = pK_b + \log [acid]/[base]$ we can find concentrations of acid-base pairs to provide a buffer of an exact pH. Buffers all have a capacity which depends on the concentration of the buffers with greatest capacity when the amount of acid to base or base to acid is within about 10% of each other.” – Teacher 38

The final component of teachers’ KoSc focused on the difficulties or limitations associated with teaching the content. Some teachers demonstrated their KoSt, KoCO, or KoR when relating teaching difficulties. These statements are discussed in their respective sections below. When discussing difficulties related to their KoSc, some teachers shared comments on the content itself.

- “There are so many places to make mistakes when dealing with weak acid/base problems. To understand these problems there needs to be a deep understanding of acid base neutralization reactions, pH, pH calculations, hydrolysis, pK_a, pK_b, titrations, endpoint, equivalence point, stoichiometry, buffers, conjugate acid base pairs, acid base equilibrium, buffering capacity, indicators and the Henderson-Hasselbalch equation." – Teacher 42

- "Since these graphs are best made with technology, teaching the techniques to make their own and the skills in the lab is challenging. There is a lot of background knowledge required in the nuances of getting the most information possible out of the titration curves." – Teacher 36
- "Buffer problems are the ultimate culmination of knowledge for acid/base AP chemistry. Students need to have a solid understanding of log terms, ionization constants (including K_a, pK_a, K_b, and pK_b), writing and solving equilibrium expressions, and acid/base conjugate pairs. Throw in the Henderson-Hasselbalch equation, which they learn during this topic and it can be quite overwhelming. A deficiency in any of these areas can lead to major difficulties in solving buffer problems." – Teacher 45

Teachers also shared limitations based on their own background knowledge and comfort level with the material.

- "I haven't had much experience with completing or teaching titrations and haven't really spent any time learning about them. I will have to put in some significant prep time before I would feel comfortable teaching this topic to my students." – Teacher 11

- "My personal limitations include the level of comfort I have with the topic. I'm still trying to increase my abilities and activities within the subject matter." – Teacher 44

When describing the importance of teaching buffers, one teacher demonstrated their KoSc by providing real-world examples of buffers.

- "Aspirin is buffered since acetylsalicylic acid is acidic and could irritate the stomach. Alka-Seltzer includes sodium bicarbonate and citric acid so that in water it produces sodium citrate and bicarbonate. The citrate ion reacts with hydrogens in acids. The bicarbonate ion reacts with hydrogen and hydroxide ions depending on conditions. Buffers also are responsible for keeping blood pH at 7.4. Carbon dioxide in the blood is buffered by phosphate and serum protein buffers to prevent carbonic acid production. The ocean is buffered by a bicarbonate system in order to prevent a change in ocean pH, protecting marine life." – Teacher 37

<u>Summary of KoSc</u>

Participants described their equilibria topic choice, intentions for student learning, and difficulties or limitations associated with teaching their topic. The main themes for KoSc were:

- Teachers were able to share intended learning outcomes for their chosen topic by detailing the foundational components of the concept. This branched their KoSc and KoT, which demonstrated their PCK.
- Despite participants' lack of experience with teaching their chosen topic, they anticipated challenges with the content and their level of prior knowledge and

experience. Teachers were able to prepare for teaching a topic despite their own personal limitations, demonstrating KoT.

- Teachers expressed knowledge that they possess above what their students need to know about equilibria topics, which demonstrates KoSc that they gained through the CHEM 773 course.

Examples of KoG

The next code for the CoRe assignment relates to KoG, which may include learning goals for scientific literacy, real-life application, and integrated understanding.[41] Participants revealed their KoG by describing the importance of learning their chosen concept. Many teachers felt that their concept provides foundational chemistry knowledge or connects to other topics in their chemistry course. By discussing the importance of this chemistry content knowledge, teachers also exhibited their KoSc. Some examples are given below.

- "This topic is important for students to know about because it provides a way to accurately determine the concentrations of various substances or solutions. In addition, titrations can be used to help determine properties of solutions, properties such as pH, equivalence points, and K_a or K_b. There are also aspects of stoichiometry in titrations, so titrations can help and reinforce some of the main ideas of stoichiometry." – Teacher 11
- "It is important for students to have additional information about what slightly soluble and insoluble really mean in chemistry. The Ksp value is an opportunity for students to see the quantitative side of solubility. Equilibrium and Le

Châtelier's principle are essential chemistry topics that I do not spend enough time exploring in regular chemistry." – Teacher 9

- "Equilibrium reactions are an important aspect of chemistry. The concepts of equilibrium can include most acid-base interactions, as well as solubility and phase change reactions. Beyond chemistry, many biological systems use reversible reactions to counteract environmental changes to maintain homeostasis." – Teacher 40
- "Equilibrium allows us to predict the direction of chemical reactions and calculate the composition of the final reaction. It also allows to control the reaction conditions to favor the formation of desired products." – Teacher 44

Four participants noted the importance of helping students develop graphing skills.

- "It is important for students to know this topic because it is reading a graph. This concept is difficult for students and the more exposure and lessons over graph reading will help students." – Teacher 14
- "By constructing and analyzing the titration curve, students will practice this skill by looking for patterns and relationships in the graph that they have not seen before." – Teacher 29
- "It's crucial to read and interpret graphs and derive different levels of meaning from the data." – Teacher 36
- "Reading graphs is also a skill that can transfer many times over." – Teacher 6

Several teachers found it important to prepare their students for future science education.

- "These concepts…will be presented to them fairly quickly in college if they start second semester or second quarter chemistry as their first class. Knowing about the behavior of acids (and bases) will come up in future biology classes as information regarding the human body (enzyme behavior, stomach acid digestion and other biological factors)." – Teacher 43

- "Students will see this concept again in a Freshman Chemistry college course." – Teacher 22
- "A majority of my AP chemistry students are also going to pursue science/medicine in college. A solid foundation with buffers will help them succeed in their future." – Teacher 45
- "Considering the courses in which I would be teaching this idea, most of these students would be college-bound. Equilibrium is covered in advanced general chemistry courses, such as the CHEM 112/114 sequence… If most students are college-bound, I feel that getting them exposed to this idea will give them an advantage when it comes to their general chemistry courses in college." – Teacher 5
- "Students will need to know this concept as they advance through high school science courses. This concept can be applicable to biology, chemistry, anatomy and physiology and many more." – Teacher 39
- "Titration is also an important skill to have entering college chemistry." – Teacher 4

Similarly, other teachers found importance in preparing their students for future careers.

- "A lot of jobs require students to evaluate a certain phase, and possibly change it to another phase. Most trades involve heating/cooling of metals or other elements. Many chemicals we use today will change phases at relatively low temperatures…Reading graphs could help when following a procedure at a factory or for a certain machine as many of the directions include some type of graph reading/analysis." – Teacher 6

- "Equilibrium also introduces students to a more realistic understanding of chemical reactions, which may be important, especially if they are going into a STEM career." – Teacher 5

Connecting to their KoCO, several teachers discussed their topics relevance to the AP Chemistry exam or other standardized tests.

- "Reading graphs…would help with ACT/SAT." – Teacher 6
- "Students in AP Chemistry will absolutely be presented with these concepts…They will come across the topic on the AP test." – Teacher 43
- Students "need to know this information for the AP test." – Teacher 36
- "In order for students to be successful on the AP Chemistry exam, understanding the reactions of acids with bases and how weak acids/weak bases interact with their conjugate species to make buffers is imperative." – Teacher 41
- "Students will be asked these types of questions on the AP Chemistry exam." – Teacher 22
- "In order to maximize their score on the AP test. Students must be able to recognize a buffer solution, understand how a buffer solution works, and be able to apply the H-H equation or use an ICE table to solve a buffer problem." – Teacher 45
- "Equilibrium…is also covered on the AP Exam, which would make it an important topic to cover." – Teacher 5

Finally, teachers discussed the relevance of their chosen topic to everyday life.

- “Phases of matter are something students encounter every day.” – Teacher 6
- “Phase changes are constantly occurring around students. Understanding and identifying where those changes are occurring will help them apply chemistry to the world around them.” – Teacher 14
- “Equilibrium systems are incredibly important to biological systems and can be seen in many real-life situations. Students should be able to see the relevance and application of understanding Le Châtelier’s principle, the importance of maintaining equilibrium, and how other chemistry topics, such as acid/base and solubility, are examples of equilibrium systems.” – Teacher 25
- “A complete understanding of a buffered system is also very relevant to daily life and has many applications to biological systems and how they function properly.” – Teacher 41
- “Buffers play important roles in the world, especially in the areas of biology, environmental science and medicine. They are also used for preservative systems. Buffers are really equilibrium problems.” – Teacher 37
- “Titrations have real world applications in food processing, manufacturing, and testing water quality. This would also hopefully correct a common misconception among beginning chemistry students who can easily mix up concepts of strong vs weak acids or bases and concentrated vs dilute acids and bases. This is an important distinction in assessing hazards in the lab.” – Teacher 4

Some demonstrated their KoSc by presenting real-world connections they could share with students.

- "pH will be important for items in everyday life as they age. I know dentists are very unhappy with all the acidic foods we eat because it destroys the enamel on your teeth. I think knowing any of this information is important for class and for life." – Teacher 43
- "Equilibrium and Le Châtelier's have thousands of real-life examples like drying clothes, demineralization and remineralization of the calcium in our teeth, the fizz in a bottle of pop, photochromic lenses, the Haber process and the list goes on and on." – Teacher 44
- "There are environmental and biological issues that one could use [to emphasize the topic's importance]. For the environmental issues, we could get into the problem with acid rain and why it is or was a problem for lakes in the northeastern part of the United States. One could also come have students come up with their own plan to combat the issue and restore lakes to normal pH levels. On the biological side, blood has a buffering system that keeps the pH around 7.4. As a teacher, you could have students explore and research the buffering system in blood and the result of blood that is altered from its normal pH." – Teacher 38

One teacher reflected further on their goal of showing students that they have the capacity to understand science. This knowledge would provide them with the scientific literacy that could help them later in life.

- "I like to think that while I haven't convinced all [my students] to go into science…that they can all make it through a science class. They can all take the metric system skills, the measuring skills, the application/evaluation skills that they have learned from chemistry and go do their choice of activity with a logical and data driven perspective. I think that learning the skills of laboratory science can help with skills such as measuring in cooking, analyzing data for any class, as a parent of mine in science once told me, it allows you to evaluate others with a pretty good "bull****" detector that you might not have otherwise. You can take a complex group of numbers and turn them into something after you have taken the time to evaluate for yourself. It is so easy to just take numbers and let others interpret them for you, but I like to think that our physics, chemistry and statistics classes at school teach the actual application of all of those earlier math processes so you are now doing math for a reason." – Teacher 43

Another teacher reflected on their goal of allowing their students to experience a higher level of chemistry experiments.

- "Students will experience a college-level experiment for which they need to use a specific glassware. A lot of labs we do in my regular chemistry class are about food chemistry or connection to real life (making ice cream, launching rockets). There are a few experiments that have a setting of an almost college style lab. By doing titration lab at the end of the year when students have already gained enough experience working with chemicals, following safety protocols, and having enough chemistry knowledge, they can experience 'next level' chemistry." – Teacher 29

<u>Summary of KoG</u>

Through sharing the importance of teaching their chosen topic, participants revealed their KoG. The most common themes for KoG were:

- Teachers made connections between their chemistry content knowledge and their goals for student learning, demonstrating their PCK through their ability to branch their KoSc and KoG.
- Participants found importance in providing their students with foundational chemistry knowledge and skills to prepare them for future science education, future careers, standardized testing (KoCO), and the scientific literacy in everyday life.
- Teachers were able to identify a wide range of applications related to equilibria topics, which reveals how content knowledge gained in CHEM 773 can be applied to their teaching through real-world examples.

Examples of KoSt

The next code is KoSt, which may focus on different learning levels, needs, interests, prior knowledge, ability, learning difficulties, and misconceptions.[41] First, teachers ($N = 19$) identified the class to which they would teach their chosen topic. Many teachers chose to teach their concept in an advanced chemistry or biology course, such as an AP or Honors course ($N = 15$). One teacher chose to teach their concept to an advanced course because they "feel that some students in General Chemistry struggle with math and even the conceptual understanding of chemistry, so time would be better spent on solidifying more basic concepts than to attempt this more difficult concept." Several teachers chose to teach their concept to a general chemistry course ($N = 8$). Four teachers identified both AP/Honors and general chemistry as their student learning context. One teacher chose to bring the topic into their physical science course.

Many teachers chose their CoRe topic due to their knowledge of students' prior knowledge and learning difficulties. Several teachers discussed their students' challenges with math and graphing.

- "Students struggle with seeing a graph and interpreting what is going on, especially at a molecular level. Phase diagrams have a lot of information on them and I have found that these graphs are most confusing to students." – Teacher 6
- "The reason for this is that students know specific math relationships between x and y (linear, exponential, and others) represented as graphs, but they have never seen a titration curve graph in their life before. It will be challenging to apply the graph knowledge to the new type of graphs. In addition, a lot of students struggle with graphing data and then analyzing the graph they constructed." – Teacher 29
- "I chose Ksp as my topic, not because it is the most difficult topic of the Chem 773 course but because it would be difficult for most of my regular chemistry students…This topic will be more difficult for regular chemistry students because it is quantitative and the majority of my regular chemistry students struggle with the mathematical portion of chemistry." – Teacher 9
- "Overall, I think my students are sometimes weaker when it comes to graphs and all that they can mean (kinetics and order of reactions also comes to mind here)." – Teacher 36
- "I feel at the high school level, students struggle with the manipulation of math problems or transferring conceptual relationships to math problems." – Teacher 5

One teacher explained that, although their chosen topic is challenging, it would be manageable for students due to their level of prior knowledge.

- "The reason I chose [buffers] is because even though the concept of acids and bases may not be a difficult one to learn, students will have to have a solid knowledge of strong v. weak acid/base as well as that of conjugate acids/bases and salts of conjugate acids/bases." – Teacher 38

Teachers also anticipated challenges their students may face when learning the challenging concept.

- "I believe [titrations] could be difficult for students because of all the information they need to have a handle on in order to complete them and their calculations." – Teacher 11
- "While the equations for K and Q are the same, students may confuse the idea of a reaction being assumed to be at equilibrium when it's not." – Teacher 25
- "Students have a difficult time determining which combinations of solutions can and cannot make a buffer and at what point during a titration they have a buffered solution. I think it is primarily because they have to think about what species are in solution and that is tricky." – Teacher 41
- "Acid/base titrations are difficult to teach, because there are so many options for how to ask and answer questions associated with this topic. Students like a process, and these problems give them so many options, they get confused as to what to do." – Teacher 22

When discussing the difficulties and limitations associated with teaching their concept, many teachers gave statements relating to their KoSt. Again, teachers described their students' struggles with math, graphing, and data interpretation.

- “Students struggle with graphs. They associate it with math and that turns a lot of them away.” – Teacher 6
- “Students’ struggle to be able analyze graphs and interpret the data.” – Teacher 29
- “The most important difficulty is low math abilities. Many of my students have poor algebra skills.” – Teacher 9
- “Many students will have difficulty with the mathematical expressions and calculations. Many equilibrium expressions involve working with exponents. Students may have difficulty with knowing when they are allowed to assume that the shift is negligible compared to initial concentrations. Students may have difficulty with setting up ICE tables correctly.” – Teacher 40
- “In order to properly teach students to calculate solubilities and to calculate reaction quotients, students will need strong abilities in working with scientific notation and manipulating equations. Students often struggle with typing scientific notation into their calculators, as well as conceptually understanding a big number written in scientific notation versus a small number written in scientific notation. This problem is typically more prevalent in my general chemistry class than my honors chemistry class.” – Teacher 5

Teachers also discussed their students’ difficulties understanding or visualizing abstract concepts.

- “Abstract thinking skills are not entirely developed yet for younger people. Many will just do the math and hope they get the numbers plugged into the correct spot. They won’t actually comprehend why the color change is occurring. They do often have a pretty firm grasp of how LCP works now as it was one chapter ago and they could get the left right 'Shift' idea down, but it is hard for them to visualize on their own." – Teacher 43

- "Difficulties for students include the fact that there are no observable changes as time goes by when a system is in equilibrium, making it hard for students to visualize." – Teacher 44
- "The idea of chemical equilibrium is abstract, so this topic is difficult for students in general. These problems also include stoichiometry and analogical reasoning…Students often take an approach of memorizing steps and equations. It will be important to help guide students in taking a problem-solving approach." – Teacher 37

Teachers then talked about the challenges that the difficulty of the content itself poses. They emphasized the need for students to have a firm grasp of the concepts before moving forward with the lesson.

- "In order to understand buffers, students must first have a good conceptual grasp of chemical equilibrium and acid/base chemistry. Students need to understand the chemical species involved at the molecular level, which is very difficult." – Teacher 41
- "Content-wise, I feel that calculating equilibrium concentrations and solubilities are usually taught separately from Le Châtelier's principle. I feel that in order to achieve this bridge of conceptual understanding between equilibrium constants/reaction quotients and Le Châtelier's principle, students will need strong understandings of each before I am able to bridge the understandings together." – Teacher 5

Two participants remarked on how their students struggle to be more independent during lab activities.

- "With my experience with students and labs, I feel as though I would have to hold all my students' hands through the whole process." – Teacher 11
- "Students do struggle to follow lab directions. They have a habit of relying on me to tell them step by step what to do rather than actually making an effort with the printed directions. Another thing that they struggle with that I am pushing for here is that they tend to memorize steps and avoid making inferences that require deeper understanding. Since until now all I have done with weak acids and bases is explain what they are and give examples the questions at the end would challenge them in this area." – Teacher 4

Participants talked about points of confusion or difficulty for students due to their current level of knowledge on the topic. Students also may not have been exposed to the chosen topic, so some challenges stem from a lack of prior knowledge.

- "Students are going to be knowledgeable about water's phase changes. They have seen and possibly do those phase changes. Other substances like a gas they will be confused about, especially because the gas phase is the only phase they have seen for substances like carbon dioxide." – Teacher 14
- "Students will have difficulty in picking out the acid-base pairs of a given chemical equation. It is not easy for students to grasp the idea of a conjugate acid or conjugate base – especially from equations that they have not seen before." – Teacher 38

- "Students typically struggle with this topic because of the quantity of steps that must be completed, and the variety of methods used to work the problems. This topic requires students to remember quite a bit of information from previous topics and apply it in a new way, which is hard for students." – Teacher 22
- "Titrations of monoprotic acids…traditionally have been difficult for students to understand completely." – Teacher 42

Teachers were then asked to share their knowledge of students' thinking and how that impacts how they teach their chosen topic. Participants first shared their knowledge of students' learning preferences.

- "I would think about how my students learn best, based on the various learning styles in education: visual, auditory, reading/writing, and kinesthetic. I would incorporate each type of learning style into my teaching so that my students would get instruction in a variety of styles." – Teacher 11
- "My students are very hands on but lacking in math, so I need to start simple, and work on building from that foundation. They have excelled when they can see something happen and then we discuss it and they can think back to that scenario. They do better with paper graphs, so most of the activities will be printed rather than virtual." – Teacher 6

Teachers then discussed their past experiences of student interactions with the chosen topic (N = 12). They then explained how they would approach instruction in light of these experiences. A selection of examples is given below.

- "Students have a black and white understanding of precipitation. Some students struggle with what is occurring during a precipitation reaction. Students have a limited understanding of solvation and concentration. Some students struggle with interpreting the solubility trends information, especially the exceptions." – Teacher 9

- "Students have a hard time visualizing what is occurring in the solutions as a titration is occurring. They also have a difficult time understanding what occurs at the equivalence point." – Teacher 42
- "Students want to reduce the complex chemistry of a buffer question to plugging in numbers in the Henderson-Hasselbalch equation without understanding the chemistry involved. When students figure out that they have a buffer question, then they try to determine the easiest mode of finding the answer. They do not stop to think about the actual molecular interactions between chemical species." – Teacher 41
- "One of the most common mistakes for students in buffer problems is simply not recognizing that it is a buffer solution. In other words, they are not confident in identifying the chemical formulas as strong acids/bases, weak acids/bases and the conjugate pairs associated. Students also get overwhelmed." – Teacher 45
- "I feel that students would have a difficult time learning this concept. They would feel it is too technical and the vocabulary would pose trouble to them." – Teacher 39

One teacher reflected on their students' reactions to the annual titration lab. The teacher discussed how the lab was the culmination of the knowledge students had gained throughout the year and shared observations of their students' behavior during the lab experience.

- "I find year after year that the students are really into this big final titration lab as we finish up through the end of May. It is like they see the need for the numbers to make measurements of moles match. They start to see the 1:1 and 1:2 and 1:3 proportions having an effect on things and the balanced equations start to really set in. They have had a whole year to learn so many different pieces of the chemistry puzzle and a lab that lasts five days and requires constant repetition to be good at it is so fun to watch. Listening to them 'groan' over the bad pink that totally overshoots the mark even 0.5 mL past the desired equivalence point is the mark of a student who really wants to get it right." – Teacher 43

Participants then discussed potential misconceptions associated with their chosen topic. By sharing misconceptions, teachers demonstrated their PCK through their KoSc and KoSt.

- "I feel that students may struggle with the concept of equilibria, because they have a preconceived notion that only physical changes are reversible so making sure I take the time to talk about reversable reactions." – Teacher 44
- "I believe that students will have a hard time with the term 'salt.' They will always go to the place where salt means 'sodium chloride' – table salt. They will fail to see or understand that the term salt means a product from the cation of a base and the anion of an acid – of which NaCl is one but could mean any combination of the like ($NaCH_3COO$, K_2SO_4, etc.)." – Teacher 38
- "Common Misconceptions: Misidentifying conjugate acids and bases and if they come from strong/weak acids and bases. Leads to incorrectly identifying buffer solutions; Incorrectly identifying if a soluble salt will generate an acidic, basic, or

neutral solution." The teacher included four additional misconceptions. – Teacher 45

- "A common misconception is what is happening on a molecular level with phase changes. Students do not realize how all molecules are moving, including the ones in a solid. When heat is added into the molecule, the speed at which the molecules are moving increase which induces a phase change." – Teacher 14

One teacher included a reference to the literature when identifying common misconceptions for their chosen topic. This connects their KoSc, KoSt, and KoR, thus highlighting their PCK.

- "There are quite a few misconceptions known to occur when students are learning buffers (Sullivan, 2012)." The teacher then included thirteen common misconceptions. – Teacher 37

Teachers then described how they would correct misconceptions, with touches on their KoT and KoSc, thus demonstrating PCK.

- "I also hope to eliminate some misconceptions that I am not sure I have taken enough time to address in the past so students are better able to define strong vs weak acids and not assume that weak acids are not as hazardous as strong acids." – Teacher 4
- "Students might think the line for a phase diagram will be linear. A way to help students with their thinking would be to plot out the data during a phase change. This would visually help students see how phase diagrams are not always linear. Another thought that students will have is how phase changes are only affected by temperature. Demonstrations to show how pressure affects phase changes also

> would help. Whether it is videos of the demos or actual demos done in class. It depends on the materials and equipment needed." – Teacher 14

Summary of KoSt

In order to demonstrate their KoSt, teachers shared their past experiences with students. Through prior instruction, teachers became aware of common student misconceptions, learning struggles, and reactions to content that they could expect during future teaching. The main themes for KoSt were:

- Teachers' awareness of students' prior knowledge and skill level allowed them to tailor their instruction to their students' learning needs. This combined their KoSt, KoSc, and KoT components of PCK.
- Participants demonstrated their KoSc by detailing common student misconceptions, again combining multiple components of PCK (KoSc, KoT, and KoSt).
- Teachers emphasized their students' struggles with math, data interpretation, and graphing and discussed how this would cause students to face challenges with the chosen topic.

Participants' KoSt allowed them to create a CoRe that would better support student learning, as well as prepare the teachers themselves for future instruction of a challenging concept. The common intertwining of PCK knowledge bases in teacher responses indicates improved PCK due to their participation in MS program courses.

Examples of KoCO

The next code describes KoCO, which may relate to state and local standards.[41] In the CoRe assignment, teachers are asked to name the standards that are relevant to their chosen topic. Most of the teachers provided NGSS standards (*N* = 13), while many provided AP learning objectives (*N* = 7). Two of these teachers included both NGSS and AP standards. Two teachers gave state-specific standards related to their chosen topics.

When making choices about what details to include in their instruction of their chosen topic, some teachers discussed time limitations.

- "I think the common ion effect and effect of pH are pieces of information that could expand on the idea; however, these concepts could be optionally covered depending on pacing. I think that these would be concepts that could be grasped by students, but may take more time, especially in the case of AP chemistry where there is a laundry list of concepts to cover…With teaching any topic, I feel that time is one of the biggest limitations that I would have. Even now, we just covered equilibrium, meaning that this topic would most likely be covered towards the end of the year. With that, the time allotted for this topic depends on the time spent on previous concepts throughout the year." – Teacher 5
- "I will not be spending much time on the triple point in this CoRe. There just is not time." – Teacher 6
- "This can be difficult to teach because of the time it takes to fully expose students to the variety of problems and provide time for them to practice multiple times." – Teacher 22
- "One of the key difficulties I face with acids and bases is time constraints and bulk of material, there are so many calculations we could do if we had time, we just don't so I wanted to keep this to something that I could realistically cover in my current class with the time I have." – Teacher 4

Multiple teachers discussed teaching their chosen concept either because the topic was included in the standards.

- “Titrations of monoprotic acids are part of the AP Chemistry curriculum.” – Teacher 42
- “It is part of the standards.” – Teacher 46
- “I would teach this to my AP class since it’s part of the AP curriculum.” – Teacher 36

Participants also described the process of ensuring that their topic connects to a relevant standard.

- “Another difficulty will be to connect the idea of the Ksp table to the concept of equilibrium and the NGSS standard.” – Teacher 9
- “One of the eight science engineering practices (NGSS) that students need to learn in science classroom is to be able to analyze and interpret data.” – Teacher 29

Summary of KoCO

Teachers demonstrated their KoCO by aligning their instruction with relevant standards and making informed decisions about what topics to include in their instruction. The main themes for KoCO were:

- Teachers were able to identify the standards that best related to their chosen topic. Therefore, teachers understand how they can integrate new equilibria and acid-base chemistry concepts into their instruction.
- Time limitations were a concern for teachers who wanted to bring new topics into their instruction. Participants made realistic decisions about what could be

covered in their courses, which demonstrated PCK through their KoCO, KoT, and KoSc.

Examples of KoT

The next code is KoT, which involves the discussion of teaching methods and activities.[41] First, teachers were asked to share the teaching procedures related to their chosen topic. Most teachers utilized multiple teaching strategies for their CoRe lesson. The top three instructional strategies were practice problems ($N = 15$), labs or demonstrations ($N = 14$), and direct instruction ($N = 14$). Multiple teachers ($N = 5$) included group activities that involved creative applications of the concepts. Others included discussion ($N = 2$) or simulations ($N = 1$) in their CoRe lesson plans.

When sharing their teaching procedures, one teacher explained the reasoning behind each teaching method choice. This reflection reveals the teacher's KoG, KoT, KoSt, and KoSc and, therefore, their overall PCK.

- "This provides students with the basic language for the concept and an introduction to the solubility rules…This encourages students to think about what is occurring at the micro and macroscales. The chemical equation represents the chemical process at the macroscale and the particle drawings represent the chemical process at the micro scale. It requires student communication, model making, and representing change associated with a chemical reaction… This activity will provide students an introduction to a quantitative evaluation of solubility and the range of meaning of the words 'slightly soluble' and 'insoluble'… This activity provides students with an opportunity to practice and use their skills to predict solubility utilizing their new knowledge of Ksp values in addition to the traditional solubility rules. This also gives students an opportunity to perform solubility tests, record, and evaluate data." – Teacher 9

The next CoRe prompting question asked participants to share what factors influence their teaching. Multiple teachers shared their KoSt by discussing their students' level of prior knowledge, especially in middle school science courses.

- "The next 2 years of juniors at my school missed all middle school chemistry standards, so they are coming in blank slates. The Covid-19 pandemic robbed them of this information. This will mean we will need to be more explicit the next few years and direct with all of our chemistry teaching. The freshman this year had never heard of an atom, element, proton, neutron, or electron. Even the A+ students." – Teacher 6
- "One important factor is the students' prior knowledge from their middle school science classes. Most of their experience with chemical reactions will be irreversible reactions. Students will have some prior knowledge of acids and bases. Most students will be enrolled in Math 2, so will not have experience with logarithms, but should be able to manipulate exponents." – Teacher 40
- "Depending on the ability of my students, I would have to limit the amount of material covered and the depth to which it is covered." – Teacher 11

Several teachers mentioned the impact of students' prior knowledge on what and how they teach. This connects to teachers' KoSt.

- "We have already covered acids and bases, as well as solutions (solubility), so I can add in extra questions on the worksheets where students have to write dissolution reactions and determine conjugate acid-base pairs." – Teacher 25

- "In teaching this idea, I feel that I will take into consideration my students' mathematical abilities, especially when it comes to pulling information from word problems and being able to use the correct equation or solve for the right variable. If my students for the year prove to struggle with those math skills, I may be more hesitant to implement reaction quotients, as it may be difficult for students to understand what exactly they are solving for." – Teacher 5
- "I will need to revisit variables and graphs topic by starting from basic graphs to activate their prior knowledge and then guide them through some scaffold on how they can apply this knowledge to titration curve graphs. This can be done one or two days before the experiment." – Teacher 29
- "A lack of understanding basic chemical equilibrium forces students to rely on plugging numbers into equations which is detrimental to the development of conceptual understanding and long-term learning. This affects their molecular knowledge of the interactions between chemical species involved in the acid / base reaction (i.e. buffers are difficult!)." – Teacher 41

Participants also described their students' reaction to the material. Teachers used their KoSt to anticipate students' reception of their chosen concepts.

- "Other factors could be how perceptive the students are to the subject. If students seem to take the subject easy, I would move on from it faster. If students seem to be having difficulty getting the topic, I would restructure the material and do my best to present it in a different fashion." – Teacher 14
- "The concept of buffers and buffering are difficult for students to grasp." – Teacher 42

- “Being at the end of a semester, students are already worried about other big projects that are due in other classes. I can literally see the stress in many of the students’ faces. They really don’t want to be challenged in any of their classes, although I often must be like a cheerleader and keep pushing/rooting them on to finish strong. This problem becomes magnified even greater at the end of the school year and their focus is not even on school. Many students go into ‘coast’ mode by this time.” – Teacher 38
- “My students tend to get overwhelmed when there are a lot of different equations, so I keep my focus a bit narrow. That eliminates much of what we have covered in the equilibria class but at least gives a broad understanding of the topic without the intricacies. What I would like to do better on is connecting the math they do understand to the concepts, and I think titration is an important part of that which graphing makes about a thousand times more clear when they see the change in pH rather than just the change in color.” – Teacher 4

Two teachers discussed how their own level of prior knowledge or experience impacts how they would teach their chosen concept.

- “Also, I am no expert in titration problems and calculations and the topics related so I would need to spend an extensive period of time preparing for my lessons. If I was unprepared the students would notice, and it would be difficult to get them to buy into what I am teaching about.” – Teacher 11
- “I struggled a little bit with this concept, so I can see where student misunderstandings can occur.” – Teacher 46

Connecting back to teachers' KoCO, time constraints also impacted how participants planned to teach their chosen concept. Teachers are impacted by when their content appears in the curriculum and how long they are able to devote to their topic in class.

- "Number one on my list is TIME. I'm concerned about making this a meaningful introduction without incorporating too much detail that could lead to the need for additional instruction/reinstruction." – Teacher 9
- "This topic will be taught in the spring at the end of the year (beginning of May) and sometimes this is the subject that gets cut when we have time restraints. This also means that the activities need to be really engaging that way I can keep students focus at the end of the year." – Teacher 44
- "First is time constraints. It is always the case that our unit on acids/bases fall at the end of the semester, so we may have anywhere from 5 to 10 class periods to teach all the concepts that go with this unit. That means we must teach acid/base theory, equilibrium constants, calculating pH and do titrations all before we can get to buffers. What that means is that if all goes well, we could have 2-3 days of working with buffers at best, to none depending on time." – Teacher 38
- "A major factor at this point in the AP curriculum is the amount of class periods left until the AP test. Ideally, I'd like to devote three full class periods to buffers. I'm not sure that is realistic." – Teacher 45
- "The biggest factor influencing the teaching of this content would be time. Our physical science team only teaches chemistry during the first semester. We immediately switch to Physics at the start of the second semester due to student schedules being changed." – Teacher 39

- "Unfortunately, I don't think our class periods are long enough for my students to successfully set up, titrate small amounts and graph in a single period so until I can get the equipment to automate the process more, or if my students are already experienced in titrations, I think the best way to do it is to focus in on it in the post lab." – Teacher 4

Again connecting to participants' KoCO, some teachers described the impact of the AP framework on their teaching choices, including the depth to which they teach the topic, when they plan to incorporate the topic, and whether or not the topic will help students prepare for the AP test.

- "I am actually really glad that the AP curriculum decided to focus solely on 'before titration,' halfway point of titration and equivalence point. I think these three being the key components of the topic give it a direct focus that helps us leave out the, "pH every 5 mL" calculation process." – Teacher 43
- "There are multiple layers of tie-in to different types of AP questions from being able to read and analyze titration curves. From stoichiometry math to Ka values and particle diagrams. Titration curves are all but guaranteed on the test." – Teacher 36
- "Another note is that the curriculum taught is guided by AP Chemistry so students will just be learning what they need to know for the exam as guided by College Board." – Teacher 37
- "In terms of an AP course, I feel that this [lesson] can be an application that combines a couple different concepts that they need for the AP test." – Teacher 5

One teacher described their creation of a resource to better support student learning.

- "To help with the numerous steps involved and many options for how to solve the problems, a flow chart will be created to help guide students through working the problems." – Teacher 22

Summary of KoT

All teachers outlined their teaching procedures, which incorporated multiple teaching strategies. Participants also discussed additional factors that influence their teaching. The main themes for KoT were:

- Teachers differentiated instruction for their instruction of equilibria topics, incorporating students' prior knowledge, students' reception of the material, and teachers' own prior knowledge into their teaching choices. This combines their KoT, KoSt, and KoSc, which supports improvements to their overall PCK.
- Time constraints and standards restricted participants' ability to teach their chosen concept in depth; however, these factors guided teachers' lesson plan. These aspects connected to teachers' KoCO, a component of PCK.
- Participants were able to describe how they would adapt instruction based on what student learning is taking place. Teachers demonstrated their KoG, KoSt, and KoT by creating a CoRe that takes into account students' prior knowledge and learning preferences.

Examples of KoA

The next code is KoA, which details teachers' knowledge of formal and informal assessments and feedback.[41] Most teachers ($N = 17$) discussed how they would assess student learning. The three teachers that did not describe assessment methods appeared to misunderstand the relevant CoRe prompting question. Many teachers mentioned assessment methods in the teaching procedures section of the CoRe.

- “We would have…an assessment at the very end to determine the students’ understanding of the concept. The assessment will help me to determine if I need to go back and reteach anything from the lecture and notes.” – Teacher 11
- “Activate and assess students’ prior knowledge with a pre-assessment.” – Teacher 40
- “Equilibrium Unit Test: Students will demonstrate whether or not they understand equilibrium concepts. Questions will include writing equilibrium expressions, determining if Q=K, using Le Châtelier’s principle, and whether a reaction is reactant or product favored.” – Teacher 25
- “Quizziz Check: Online quiz game to check students understanding in an interactive, low stress activity in the form of a game.” – Teacher 44
- “Students will also be given several assignments, including a Take-Home Quiz, linked here.” – Teacher 41
- “I feel that I would also incorporate a summative assessment to determine if students have a solid enough understanding before moving further.” – Teacher 5

Teachers then discussed how they would assess student understanding or confusion. In the Spring 2023 CoRe, these assessment methods included checking for understanding through practice problems ($N = 8$), direct questioning ($N = 7$), formative or summative tests/quizzes ($N = 7$), listening to student discussions ($N = 6$), lab reports ($N = 5$), and various projects or presentations ($N = 4$). In their responses, teachers also explained their reasoning for using these assessments. A selection of responses is given below.

- "Quizziz: Give students 20 multiple choice questions in order to check for students understanding. Gives immediate feedback not only to students but to me as well. Because the site gives immediate feedback by emailing the class averages for each question and total score to me, I can use that information to determine what needs to be retaught for students to help gain a better understanding." – Teacher 44
- "I also try to use deeper, synthesis level questioning techniques with students to determine whether or not they truly understand the content or if they have a surface level understanding. I often use exit tickets to do this style of questioning." – Teacher 41
- "I'll grade the POGIL and quizzes to gain an initial understanding of misconceptions and then hopefully address them before the unit test." – Teacher 46
- "I will have students discuss their ideas with their peers first, and then we'll come together as a class and discuss what they talked about as a group. I have found, students tend to open up to their peers and are more willing to be a part of classroom discussions if they and their peers are able to come up with an idea they all agree with." – Teacher 11

Summary of KoA

Most teachers explicitly described their assessment methods by sharing their teaching procedures and discussing how they would assess student understanding or confusion. The most common themes for KoA were:

- Most teachers included multiple methods of assessment and demonstrated their desire to assess student understanding throughout the lesson with formative assessments. Through these assessments, teachers would be able to identify and correct student misconceptions, showing their KoSt.
- Teachers were able to express their reasoning behind using various assessment methods, demonstrating their KoA as a component of PCK.

<u>Examples of KoR</u>

The final code in Codebook 2 relates to KoR, which discusses materials and activities that teachers utilize in their classrooms.[41] Participants demonstrated their KoR by identifying which resources they would use in their teaching of equilibria and acid-base chemistry. In the teaching procedures section of the CoRe, teachers expressed knowledge of lab activities and demonstrations ($N = 6$), POGIL and other group activities ($N = 5$), videos, ($N = 4$) quiz software, including Quizizz and Google Forms ($N = 4$), readings ($N = 1$), simulations ($N = 1$) and research databases ($N = 1$).[80, 82]

When reflecting on their topic choice, one teacher discussed limitations posed by the resources they are currently using for their curriculum.

- "Another limitation would be finding material. For my curriculum, the book and resources provided by the school does not have a good variety of phase diagrams." – Teacher 14

Another teacher proposed using Chemix, an online resource for drawing lab diagrams, to encourage students to be more independent during lab activities.[83] Their identification of this software demonstrates their KoR.

- "I am hoping to move away from [telling students step by step instructions] and think that using Chemix would help them take this step." – Teacher 4

Summary of KoR

Teachers demonstrated their KoR by providing links to readings and videos, attaching files of worksheets, and describing activities and software they plan to use during instruction. Teachers also discussed current challenges they face in their classrooms that could be remedied through the use of better teaching resources.

Summary of CoRe Data

In Semester 4, teachers participating in the CHEM 773 course created a CoRe for an equilibria or acid-base chemistry topic. Participants were able to express their content and pedagogical knowledge by detailing their lesson plan for a challenging topic, which demonstrated their KoSc and KoT as components of their PCK. Most teachers possessed all seven components of PCK. The main themes for the Semester 4 CoRe were:

- By understanding their students' level of prior knowledge and learning preferences, teachers were able to develop a CoRe that included teaching procedures that would support student learning of equilibria topics. All participants combined their KoSc, KoG, and KoSt to craft an effective lesson, which demonstrated improved PCK quality.
- Participants described how they would adapt instruction based on student learning, which demonstrates teachers' KoSt, KoT, and KoA and, thus, reveals improved PCK. By identifying misconceptions, teachers would be able to adjust their teaching to check for student understanding and effectively teach their chosen topic, which would improve their teaching effectiveness.

- Teachers reflected on their intentions for student learning, the purpose of teaching their chosen concept, and how their concept fits into the standards. Teachers used all PCK bases to develop a well-rounded lesson on equilibria and acid-base chemistry topics.

The majority of participants exhibited multiple components of PCK in their responses to each of the CoRe prompting questions. The blending of the PCK components demonstrates higher quality PCK because teachers are actively utilizing and combining multiple knowledge bases when reflecting on their teaching.

Module Survey – CoRe

After completing the CoRe assignment, teachers were invited to complete a survey about their experience creating a CoRe for their topic. Twenty teachers completed the CoRe module survey in Spring 2023. In the survey, participants were asked if they would feel comfortable teaching their chosen topic without preparation. Of the 20 teachers, 15 (75%) would not feel comfortable, 1 (5%) would feel comfortable, and 4 (20%) would feel comfortable teaching without preparing but would prefer to review the content beforehand. When asked about their confidence level on a scale of 1 to 6 for teaching their concept, the average confidence score was 4.62. Upon creating a CoRe for their topic, 6 teachers (30%) did not find it challenging and 14 (70%) did find it challenging, with 4 of these teachers finding only some aspects to be challenging. The CoRe module survey was coded using Codebooks 1 and 4.

<u>Codebook 1</u>

Coding frequencies for Codebook 1 can be found in Table 203.

Table 203. Module Survey Coding Frequencies for Semester 4 CoRe – CB1

Code	**Abbreviation**	**Total Number of Teachers Represented (*N* = 20)**	**Percentage of Total Responses (%)**
Attitudes	A-p	1	5
	A-c	10	50
Knowledge	K-p	3	15
	K-c	13	65
Skill	S-c	2	10
Teaching	T	18	90
Background	B	3	15
Goals	G	2	10
Feedback	F	4	20
Modules	M	9	45
Interaction	I	4	20
Reflection	R	17	85

Examples of Attitudes (A-p and A-c)

In terms of prior attitudes, one teacher discussed their attitudes as they entered into the CHEM 773 course.

- "I felt pretty good about Equilibrium overall headed into the course." – Teacher 2

When sharing current attitudes, most teachers described improvements to their confidence, particularly in relation to teaching and learning their chosen concept.

- "I feel more confident with the material" after taking CHEM 773. – Teacher 37
- "I think I am more confident on certain calculations related to my CoRe (titrations) just from more practice with complex ones in this course." – Teacher 36
- "I feel more confident going into teaching college chemistry next year." – Teacher 46
- "I am more confident moving forward." – Teacher 41
- "I am more confident that i will be able to teach the topic competently instead of just winging it." – Teacher 40
- "The module has just prepared me to be better and more confident to teach buffers." – Teacher 45

Teachers also shared how they could improve their confidence by gaining more teaching experience or developing instructional resources.

- "I would feel more confident teaching this concept by preparing more and just simply teaching it. My comfort level would increase the more I teach it." – Teacher 11
- "Being able to develop an arsenal of activities, labs, and more ways of explaining the topic will increase the confidence in my abilities." – Teacher 44

One teacher shared their fear that their students would not be able to grasp their chosen topic, which impacted their desire to bring the topic into their instruction.

- "I feel that my biggest insecurity surrounding teaching this concept would be whether this is something that my students actually could grasp or not." – Teacher 5

Summary of Attitudes (A-p and A-c)

The CoRe module allowed teachers to reflect on how the CHEM 773 course had impacted their attitudes. The main themes for this code were:

- Teachers gained confidence in their content knowledge and teaching effectiveness after participating in the CHEM 773 course and completing the CoRe module.
- Having more teaching experience or resources would support further improvements to teachers' confidence.
- One participant expressed an insecurity that their students may not be able to grasp their chosen equilibria topic, which impacts the teacher's willingness to bring these topics into their instruction.

Examples of Knowledge (K-p and K-c)

Upon entering the CHEM 773 course, two teachers described gaps in their content knowledge that inhibited their ability to teach effectively.

- "Creating the CoRe was a little more difficult for me for this content because I had little background information about this topic before this course." – Teacher 44
- "Before the course, I didn't have any background to teach buffers in a quantitative way." – Teacher 38

A third teacher shared how the course filled this gap in their content knowledge.

- "This course made topics that I likely struggled with in freshman Gen Chem understandable." – Teacher 9

One teacher reflected that the CoRe allowed them to determine their current level of chemistry content knowledge.

- "The CoRe assignment helps me to realize where my knowledge level is at." – Teacher 11

Five teachers stated that gaining more chemistry content knowledge would improve their teaching confidence. Some examples of teacher statements are below.

- "Having a more practice with the concepts themselves." – Teacher 39
- "Maybe just understanding when to use the electronegativity trend for acid strength over atom size trend." – Teacher 46
- "The more opportunities I have with a topic, the greater my depth of knowledge can become." – Teacher 44

Several participants ($N = 13$) discussed how the CHEM 773 course impacted the content knowledge they used to develop a CoRe. The example responses below demonstrate positive changes to teachers' chemistry content knowledge (KoSc).

- The CHEM 773 course "has helped me understand the content represented in my CoRe assignment." – Teacher 39
- "I feel I have a better grasp behind the why of buffers as well as the mathematics." – Teacher 37
- "This course has deepened my understanding of chemical equilibrium and showed how equilibrium conditions apply to situations that I had not considered before." – Teacher 40
- "I feel that I have a strong conceptual understanding of equilibrium from this semester." – Teacher 5

The teacher statements below describe how the knowledge teachers gained will allow them to teach equilibria topics more effectively. These examples demonstrate teachers' PCK by detailing how they bridge their KoSc, KoT, KoR, and KoG.

- "I have new ideas for demonstrations and real-world applications to move the concepts beyond the classroom." – Teacher 40
- "I feel that this deeper dive has allowed me to further understand the concept so that I can better scaffold tougher concepts for students." – Teacher 5
- The CoRe "has provided me with some great example problems, more knowledge of the content and some additional demonstrations." – Teacher 41

<u>Summary of Knowledge (K-p and K-c)</u>

The CHEM 773 course allowed teachers to develop chemistry content knowledge (KoSc). Several teachers reflected on how improvements to their content knowledge would allow them to teach equilibria topics more effectively. The most common themes for knowledge were:

- The CHEM 773 course filled gaps in participants' knowledge of equilibria and acid-base chemistry, which allowed teachers to bring these topics into their classrooms into greater detail. This bridging of KoSc, KoG, KoR, and KoT points to increased PCK.
- Participants expressed that further improvements to their chemistry content knowledge would improve their teaching confidence.
- The CoRe module itself allowed teachers to practice knowledge and skills related to their chosen topic, which helped them solidify their content knowledge of an equilibria topic.

Skill (S-c)

Two teachers exhibited their current practice of chemistry and pedagogical skill by discussing their desire to perform lab activities before implementing them in their classrooms to ensure adequate preparation and accuracy.

- “Performing the labs on my own before I let the students try.” – Teacher 39
- “I would want to run through the titrations myself to have a more accurate data set. That way, I could compare the students’ data to mine as they went. If something was off, or none of the groups got good numbers for a titration, I would still have a data set for students to use.” – Teacher 22

These comments relate to the teachers’ capacity to perform lab techniques, as well as their pedagogical skill in regard to lab preparation.

Examples of Teaching (T)

Most teachers ($N = 18$) talked about their teaching in relation to their experience creating a CoRe for a CHEM 773 topic. Multiple teachers shared that they have not recently, or ever, taught their chosen concept.

- “I have had no prior experience teaching any equilibrium concepts other than biological equilibrium.” – Teacher 39
- “I have never taught titration before, so I had to create a lesson plan from scratch.” – Teacher 29
- “I haven't had to teach buffers in a few years. It isn't in our honors curriculum and I haven't taught AP the last few years.” – Teacher 45
- “This is the first year I will teach about equilibrium and Le Châtelier’s principle.” – Teacher 44

For several teachers, it was challenging to create a CoRe lesson that supported student learning at the appropriate level. Teachers reflected on how to bring equilibria concepts into their classrooms, connecting their KoT, KoCO, KoA, and KoSc. Some examples are given below.

- "I had to really dig into what is absolutely necessary for students to learn and what is the best pedagogy to help students learn a challenging concept." – Teacher 37
- "It is one of the last concepts we cover for the year, and it gets missed a lot. It was challenging to put together a coherent unit plan that covers the necessary information without getting into too much detail. I also had to search out lab activities and demonstrations to show the concepts." – Teacher 40
- "It was easy coming up with ideas for teaching, but it was difficult thinking of assessments and making the ideas fit together in a logical order." – Teacher 6
- "I feel that as I was teaching equilibrium this year, I was thinking about how I could dive a little deeper into this concept, especially with my Honors Chem class." – Teacher 5

Most teachers (N = 17, 85%) stated that gaining more teaching experience would help them become more confident teaching their chosen topic, connecting to their A-c. A selection of examples is given below. These examples reflect the importance of participants' KoT and KoSt to their teaching effectiveness.

- "When I teach this topic at least once, I will feel more confident about this concept." – Teacher 29

- "Doing it once. This would allow me to figure out where I fall short and really clean up this CoRe and lesson plan." – Teacher 6
- "Doing it a time or two. Making mistakes and learning from them." – Teacher 40
- "Practice! I know I get stronger each year as I learn more and have a better idea of misconceptions students can have." – Teacher 37

Participants were asked to discuss how the CHEM 773 course content impacted their CoRe. Teachers expressed that the course prepared them to bring equilibria topics into their curricula, which touches on their KoSc, KoT, and KoCO.

- "I have an idea for the next time I teach chemistry, to not teach it as a unit, but to work it in to other units. Teach some in reactions, some in phases, some in thermo, and some in acids/bases. I think this could tie chemistry topics together better as well." – Teacher 6
- The course content "helped me think about how students would benefit from the topic and how to approach designing curriculum" – Teacher 14
- The course content "has prepared me to teach buffers." – Teacher 45
- "Graphing the titration curve is something that I just haven't included at all in my classes before. This also would help to give students a little better understanding of weak acids and bases which I have pretty much kept to a definition and a list of examples because of the math involved." – Teacher 4

Participants reflected on how their preparation of a CoRe enabled them to create future teaching plans (KoT), including assessment of student understanding (KoA), teaching resources (KoR), and curriculum organization (KoCO). These combinations of knowledge bases indicate improved PCK. A selection of responses is given below.

- “I definitely have misconceptions I will be looking for next time I teach this topic. I also have made adjustments to the way I'm going to teach this topic including adding in a demo and planning a lab for two classes post-lesson.” – Teacher 37
- The CoRe “made me look for other resources to use, like POGILs.” – Teacher 46
- Their CHEM 773 topic “can be introduced and taught to sophomores if scaffolded properly.” – Teacher 29
- “Hopefully the revisions that I have made to the lab will help students gain a better idea of the concepts of acids and bases and merge these ideas with the math.” – Teacher 4

Teachers also detailed specific plans for bringing their CoRe activity into their instruction, which shows the practicality of the CoRe assignment. Through this module, teachers were able to create lessons to use in their classrooms.

- “The new activity is a completely new arrow in my quiver, so to speak, for Unit 7 (along with Units 3 & 6) in my AP course, so it's had a big impact.” – Teacher 2
- “I plan to use this activity next year in the acid/base unit of AP chem.” – Teacher 22
- “This module has given me a good start on fully implementing the concept of Acid/Base Titrations into my classroom. I now have a plan laid out how I can fully incorporate my concept into my classroom and a list of difficulties/limitations that I will need to overcome in order for me to relay the information to my students.” – Teacher 11

One teacher expressed a lack of change associated with their completion of the CoRe assignment.

- “I'm still going to teach the concept in a similar manner.” – Teacher 45

Summary of Teaching (T)

Teachers discussed how the CHEM 773 course and the CoRe assignment impacted their teaching. The most common themes for this code were:

- Despite multiple participants not having experience teaching their chosen concept, they were able to create effective CoRe lesson plans combining their KoT, KoCO, KoG, and KoSc. The CoRe allowed teachers to showcase improvements to their PCK.
- Most teachers felt that gaining experience teaching their chosen concept would increase their teaching confidence and overall effectiveness.
- The CoRe module was not simply an exercise. Many teachers used the CoRe to prepare resources and lessons for use in their classrooms, demonstrating their KoT and KoR.

Background (B)

Three teachers shared information on their educational and teaching background. These statements provided context for participants’ current teaching confidence, prior knowledge, and KoT in relation to their chosen concept.

- “I haven't had to teach buffers in a few years. It isn't in our honors curriculum and I haven't taught AP the last few years.” – Teacher 45
- “It had been 35 years since I last explored K expressions and values.” – Teacher 9
- “Since this was my first year teaching chemistry, I am still fine-tuning the concepts that I want to cover over the course of the year.” – Teacher 5

Goals (G)

Two teachers shared goals related to their teaching. The first teacher's goal related to student success, while another's focused on attaining new lab equipment.

- "Ultimately, this [module] has helped me with my end-goal, the students' success in the concept of Acid/Base Titrations." – Teacher 11
- "I really do want to invest in a drop counter for this purpose." – Teacher 4

Feedback (F)

Four participants shared feedback in the Spring 2023 CoRe module survey. Data coded as feedback was sent directly to MS program instructors.

Examples of Modules (M)

In the module survey, teachers reflected on their experience creating a CoRe for an equilibria or acid-base chemistry topic. Creating or carrying out their CoRe lesson allows teachers to evaluate their knowledge and skill levels.

- "The CoRe assignment helps me to realize where my knowledge level is at, and where I need to improve to make sure my students have a good experience with the topic." – Teacher 11
- "Doing [the CoRe lesson] once…would allow me to figure out where I fall short and really clean up this CoRe and lesson plan." – Teacher 6

The CoRe also allowed participants to practice CHEM 773 concepts and reflect on how they would incorporate these topics into their instruction.

- "I think I am more confident on certain calculations related to my CoRe (titrations) just from more practice with complex ones in this course." – Teacher 36

- "The content in the course has directly impacted my CoRe because my CoRe topic is one we have discussed in class. In addition, the content has helped to give my CoRe topic some context and given me ideas on how I could fully incorporate this concept into my classroom." – Teacher 11
- "This module has added a new perspective to my instruction, and I will spend a little additional time to explore 'insoluble' and 'slightly soluble' terminology using the lens of equilibrium." – Teacher 9

Teachers expressed their desire to implement their CoRe lesson in their teaching.

- "If time I would like to try using some things from my CoRe module before the end of the year." – Teacher 6
- "This module has allowed me to develop a plan for teaching equilibrium more in depth if I decide to take that route in further years." – Teacher 5
- "The new activity…had a big impact - probably as much or even more so than any of the past ones I've developed in earlier courses." – Teacher 2

The CoRe assignment also impacted teachers' attitudes toward teaching CHEM 773 concepts.

- The CoRe "has helped me understand that I could easily teach this for my students understanding." – Teacher 39
- "The module has just prepared me to be better and more confident to teach buffers." – Teacher 45

<u>Summary of Modules (M)</u>

Through the CoRe module survey, teachers reflected on the impact of the CoRe itself. The most common themes for this code were:

- The CoRe assignment allowed teachers to self-assess their content and pedagogical knowledge related to their chosen concept. By reflecting deeply on their chosen topic, teachers prepared to bring this new content into their instruction.
- By creating a CoRe, teachers developed tangible plans for incorporating or enhancing CHEM 773 topics in their classrooms. The module allowed teachers to practice all components of PCK, so the CoRe itself provided an opportunity for PCK development.

Interaction (I)

Participants described the impacts of interactions on their teaching and learning. Two teachers discussed their desire to learn from other teachers, which would help them gain teaching knowledge and confidence.

- "Probably, role playing it out to another teacher [would increase teaching confidence]. Or discussing my plan in more depth with a teacher who regularly included this in their AP curriculum." – Teacher 9
- "It would be nice to see how other teachers approach equilibrium - what they decide to cover, what labs or activities they do, and what they're assessments look like." – Teacher 25

Two additional teachers mentioned beneficial interactions they have had with other teachers in the MS program.

- "The discussions with other teachers who have taught this subject have been beneficial to me." – Teacher 11

- "I also have a network of educators across the U.S. to connect with and share ideas." – Teacher 41

These interactions enabled MS program participants to learn in community with one another.

Examples of Reflection (R)

When completing the CoRe module survey, most teachers (*N* = 17) reflected on their learning in CHEM 773, their CoRe, and their teaching in general. Some teachers reflected on their experience creating a CoRe for their chosen concept. This reflection involved thinking about their teaching choices, which drew from their KoCO and KoT.

- "When I started searching for ideas, I found lots of cool approaches, but none that fit my style or students, so I had to combine and adapt." – Teacher 6
- "It certainly takes time to think through what it is you want to communicate to students. I know this is where all good instruction starts. 'What do you want students to know?' Then follow up with 'How will you know they know it?' and finally 'What will you do when they don't?'" – Teacher 9
- "It is difficult to try and plan out everything that is going to happen in your classroom. There are so many variables that I am unable to plan for day to day." – Teacher 11
- The CoRe "it certainly makes you think and look at your own practices when looking at why certain content is difficult to teach." – Teacher 42

Teachers also reflected on the concepts they chose to focus on for their CoRe assignment.

- "Buffers involve many different aspects of acid/base equilibria and are a challenging topic for many students." – Teacher 41

- “This concept was a bit tricky, because I had to come up with an idea that would break down the concept into more manageable pieces for students, while still covering the content.” – Teacher 22

One teacher discussed how their prior experience creating CoRes prepared them to create a CoRe lesson in Spring 2023.

- “I have done a few other [modules] through the last couple of years, so the format and the details, etc., were pretty familiar to me.” – Teacher 2

Another participant reflected on the difficulty of anticipating misconceptions when they feel like they have personally mastered the content.

- “It was challenging to consider misconceptions because to me this is pretty straight forward. I forget how students can struggle with things that seem easy or obvious.” – Teacher 36

One teacher expressed their desire to change the timing or depth of equilibria topics in their current curriculum, connecting to their KoCO.

- “I wish I could spend more time on equilibrium, or at least plan it so it's earlier in the school year.” – Teacher 25

Teachers then addressed how they could increase their confidence teaching their chosen topic. Many teachers anticipated gaining confidence through teaching their lesson and learning from their mistakes.

- “I think a big part of improving in teaching is learning from mistakes the prior year and then adjusting for the next one.” – Teacher 45
- “Making mistakes and learning from them.” – Teacher 40

- Teaching the Core lesson "would allow me to figure out where I fall short." – Teacher 6

Similarly, teachers expressed becoming better prepared to teach their topic after multiple iterations.

- "I know I get stronger each year as I learn more and have a better idea of misconceptions students can have." – Teacher 37
- "I will probably never ever feel prepared enough, but I wouldn't be afraid to teach it after preparing and teaching it for a few years." – Teacher 11

One teacher reflected on the value of continuing education.

- "It is always good to continue learning difficult subjects." – Teacher 41

Another teacher reflected on changes in their teaching effectiveness if they haven't taught a topic recently.

- "It can also be difficult to answer student questions if I haven't taught the topic in a while." – Teacher 45

Teachers were asked to reflect on how the CoRe has transformed their teaching of a CHEM 773 topic. Participants expressed their desire to bring equilibria topics into their courses.

- "The 773 course has opened my eyes to the universality of equilibria in science. I actually will use the equilibrium word more often in both Chemistry and Biology." – Teacher 9
- The CoRe module "has made me consider how to incorporate this topic into all of my science classes, not just chemistry because it amazed me how students do not understand how substances are changing states of matter." – Teacher 14

Creating a CoRe allowed teachers to reflect deeply on how they planned to integrate equilibria topics into their instruction.

- "I think [the CoRe] has [transformed their teaching]. Time will tell but it made me pause and reflect which I haven't done as this deep in a long time." – Teacher 42
- "Completing the CoRe has given me the ability to sit down and spend the time deep diving into the activities I would like to incorporate, the common misconceptions that I want to help my students avoid, and a better understanding of a topic that is not only difficult for the students but myself as well." – Teacher 44

One teacher discussed spending time reflecting on how students learn in their classroom, contributing to their KoSt.

- The CoRe module "has made me consider how to do students learn and put together information to make connections." – Teacher 36

<u>Summary of Reflection (R)</u>

Teachers used the CoRe module survey to reflect on their experience creating a CoRe while gaining chemistry content knowledge in the CHEM 773 course. The most common themes for reflection were:

- The CoRe module gave teachers an opportunity to reflect on the chemistry concepts they include in their instruction, as well as the teaching procedures they use to carry out their instruction. Teachers reflected on each component of PCK when developing a CoRe for their chosen concept.

- Creating a CoRe allowed teachers to think about how they would incorporate the content knowledge they developed in the MS program into their teaching.

Codebook 4

Codebook 4 then allowed me to break down the teacher statements by source of motivation. Each comment was assessed to determine the focus of the comment, either focused on the participant's learning, their students' learning, or the participant's teaching. Coding frequencies are displayed in Table 204.

Table 204. Module Survey Coding Frequencies for Semester 4 CoRe – CB4

Code	**Abbreviation**	**Total Number of Teachers Represented (*N* = 20)**	**Percentage of Total Responses (%)**
Learning-focused	L-f	19	95
Student-focused	S-f	16	80
Teaching-focused	T-f	20	100

All participants shared teaching-focused motivations in their responses to the CoRe module survey. Most teachers also included learning-focused (N = 19, 95%) and student-focused (N = 16, 80%) comments. A selection of teaching-focused statements is given below.

- "I have an idea for the next time I teach chemistry, to not teach it as a unit, but to work it in to other units. Teach some in reactions, some in phases, some in thermo, and some in acids/bases. I think this could tie chemistry topics together better as well." – Teacher 6
- "This module has given me a good start on fully implementing the concept of Acid/Base Titrations into my classroom. I now have a plan laid out how I can fully incorporate my concept into my classroom." – Teacher 11
- "This module has added a new perspective to my instruction, and I will spend a little additional time to explore 'insoluble' and 'slightly soluble' terminology using the lens of equilibrium." – Teacher 9

All teachers but one included comments motivated by their own learning that took place in the CHEM 773 course. Some examples are given below.

- "I feel more confident with the material. I feel I have a better grasp behind the why of buffers as well as the mathematics." – Teacher 37
- "This course has deepened my understanding of chemical equilibrium and showed how equilibrium conditions apply to situations that I had not considered before." – Teacher 40
- "It had been 35 years since I last explored K expressions and values. This course made topics that I likely struggled with in freshman Gen Chem understandable." – Teacher 9

Most teachers reflected on how their development of a CoRe and participation in CHEM 773 would impact student learning. Some student-focused statements are given below.

- The CoRe "has made me consider how students learn and put together information to make connections." – Teacher 36
- "Hopefully the revisions that I have made to the lab will help students gain a better idea of the concepts of acids and bases and merge these ideas with the math. I think their understanding of the two things may have been a bit disjointed in the past and I think this could be a step towards solving that issue." – Teacher 4
- Creating a CoRe "was challenging because I had to really dig into what is absolutely necessary for students to learn and what is the best pedagogy to help students learn a challenging concept." – Teacher 37

Summary of Module Survey – CoRe

Through the CoRe, teachers were able to practice content learned in CHEM 773 and apply these concepts to their teaching. By creating a CoRe lesson, teachers demonstrated higher quality PCK by applying their KoSc to a teaching context. Most teachers gave responses related to their own learning (N = 19) and their students' learning (N = 16). All twenty teachers described the CoRe and course's impact on their teaching. The most common themes for the Spring 2023 CoRe module survey were:

- Teachers gained confidence in their equilibria content knowledge and pedagogical knowledge by creating a CoRe for a challenging chemistry concept. Their teaching confidence increased through the development of an in-depth lesson plan for their chosen concept. By combining multiple knowledge bases, teachers demonstrated improvements to the quality of their overall PCK.

- In the CoRe module survey, participants demonstrated higher quality PCK by discussing how they would apply their KoSc to their teaching. When developing a CoRe lesson plan, participants took into account all PCK bases.
- Teachers planned to use their CoRe lesson in their classroom, which evidences that participants are taking away knowledge from the MS program and actively applying to their teaching. Thus, the MS program allows for its participants' PCK and professional development.
- The CoRe module itself allowed teachers to reflect on their content and pedagogical knowledge as they created a lesson for a CHEM 773 topic. This reflection enabled teachers to enhance and combine their KoSc and KoT, which led to PCK and professional development.

Chemistry Content Survey (post-test)

The post-content survey was used to determine any changes in participants' chemistry content knowledge resulting from their participation in the MS program courses. Only one participant completed both the pre- and post-surveys, so the data will be shown for a single participant: Teacher 9. The full chemistry content survey can be found in Appendix P. The survey consisted of three past AP Chemistry free-response questions related to the three content courses offered in the 2022-2023 academic year.[2] The content survey was scored using AP Exam scoring guidelines.[2] Scores for each question, course connections, comfort level rating, and confidence level rating data are shown in Table 205. The comfort level related to their comfort with the content of the question. The confidence level related to the participant's confidence with the accuracy of their answer.

Table 205. Post-Chemistry Content Survey Score and Analysis for Teacher 9

Question	Course Connection	Point Total	Change in Score	Comfort Level Rating (1-6)		Change in Comfort Level	Confidence Rating (1-6)		Change in Confidence
				Pre	Post		Pre	Post	
1	CHEM 773	5.75/6	+ 3.75	1	4	+3	1	4	+3
2	CHEM 774	2.5/3	+ 2.5	1	2	+1	1	2	+1
3	CHEM 775	3/3	-	2	2	-	1	2	+1

The overall score for Teacher 9's pre-content survey was 11.25/12. Compared to their baseline score of 5/12, they increased their score for the questions related to CHEM 773 and CHEM 774 by over 50%. Although they did not take CHEM 775 in Fall 2022, their score for the question was 3/3 for both the pre- and post-tests. The only errors in their post-test included not supporting an answer with a calculation and providing incorrect units for a rate constant, which pertains to CHEM 774 topics. Their results for the chemistry content survey reveals an increase in Participant 9's chemistry content knowledge resulting from their experience in the MS program.

In the pre-test, Participant 9 related low comfort levels with the content and low confidence in the accuracy of their responses. In the post-test, they described increased comfort levels and confidence for each question. This demonstrates positive attitude changes due to the MS program courses.

In order to learn more about Participant 9's experience in the CHEM 773 and CHEM 774 courses, they provided a statement in the form of member checking. This validated that their content knowledge increase resulted from their participation in MS program courses. Their statement is given below.

- "Chem 773 and 774 helped because I needed the instruction. Most of the content in Chem 773 and 774 I am not teaching to my regular chemistry course students. My college level chemistry knowledge is 35 years old. I took gen chem at [university] in 1987-88. Although I can learn by reading a textbook and looking at sample problems, I know I learn more effectively with an instructor as a guide and to experience instruction with a group of others. The most effective part of Chem 773 and 774 is the problem solving that occurs in Instructor A's videos. Hearing the steps and rationale for solving a particular problem or set of problems helps me to understand the chemistry vocabulary and the mathematical relationships. It also helps me recognize patterns. I know a lot of this math is 'use it or lose it,' so I'm hopeful that AP Chemistry is in my future or at the very least I'll just keep taking the released AP Chem FRQs."

Participant 9 described how the MS program courses impacted their content knowledge (KoSc) and described their goals of teaching AP Chemistry in the future. In addition to the narrative participant, the chemistry content survey confirmed that the MS program supports positive content knowledge changes for its participants. Thus, the MS program content courses support teachers' development of KoSc as a component of their overall PCK.

End-of-Semester Survey

At the end of the Spring 2023 semester, I sent out an email invitation to participants of CHEM 773 to complete a survey about their experiences in core MS program courses and the MS program overall during the given semester. Responses to this survey were coded with Codebooks 1 and 4 ($N = 15$).

Codebook 1

Coding frequencies for Codebook 1 can be found in Table 206.

Table 206. End-of-Semester Survey Coding Frequencies for Semester 4 – CB1

Code	**Abbreviation**	**Total Number of Teachers Represented ($N = 15$)**	**Percentage of Total Responses (%)**
Attitudes	A-p	3	20
	A-c	11	73.3
Knowledge	K-p	3	20
	K-c	15	100
Skill	S-c	8	53.3
Teaching	T	11	73.3
Background	B	2	13.3
Experience	E	1	6.7
Feedback	F	15	100
Modules	M	5	33.3

Interaction	I	12	80
Reflection	R	11	73.3

Examples of Attitudes (A-p and A-c)

When describing the impact of the MS program courses, many teachers discussed changes in their confidence with the material itself and with teaching the content. Two teachers discussed their prior confidence, with the second describing improvements to their current confidence levels.

- “Teaching chemical equilibrium and acids and bases is something that I didn't feel as confident in.” – Teacher 44
- “I feel more confident in equilibrium problems. This was a weakness in the past…I feel like I become a stronger teacher every semester… I am more confident.” – Teacher 37

Other teachers discussed improvements to their confidence that will allow them to teach more effectively or understand the concepts with greater certainty.

- CHEM 773 “has increased my…confidence to teach the content to students… I now have the confidence and maybe even the ambition to teach these concepts.” – Teacher 38
- “I have more confidence that I will be able to help my students with these content areas.” – Teacher 40
- “I feel more confident that my knowledge extends beyond what I cover in class.” – Teacher 4

- “I would say [I have gained] confidence. I sometimes feel uneasy when teaching topics that are new to me, but now I know I am able to handle difficult topics.” – Teacher 11
- “The homework sets are essential to gain the practice required to feel confident with the material… I am more confident solving all types of chemistry problems. The anxiety I once felt solving problems in front of students has dissipated.” – Teacher 9

One teacher discussed their attitude change related to their action research project.

- “I feel very prepared and capable for my action research for next semester, which was my biggest fear coming into the program.” – Teacher 5

Other teachers shared various attitude changes resulting from their participation in the MS program. These examples are listed below.

- “I wish I had the time to head out to SD this summer!” – Teacher 42
- “More sympathy for my students!” – Teacher 36
- “I think I have a new fondness of problem-solving skills.” – Teacher 38

To conclude the end-of-semester survey, eight teachers shared their positive attitudes toward the MS program. A selection of teacher comments is given below.

- “I'm very grateful that the program pacing can adapt to an individual student’s needs.” – Teacher 9
- “I have thoroughly enjoyed this program and am thankful for all the knowledge I have attained.” – Teacher 22
- “I just really love the program and enjoyed being taught by Instructor A and Instructor B.” – Teacher 37

- “I'm glad I've started this program. In hindsight, I wish I had started a few years earlier and gone slower to make it less stressful.” – Teacher 36

<u>Summary of Attitudes (A-p and A-c)</u>

Teachers shared attitude changes related to their experience in the MS program during the Spring 2023 semester. The main themes for attitudes were:

- Teachers experienced improvements to their confidence in their content knowledge and pedagogical skill, which led to improved teaching effectiveness.
- Participants expressed positive attitudes toward the MS program, including enjoyment, gratitude, and appreciation.

<u>Examples of Knowledge (K-p and K-c)</u>

Three teachers discussed their level of content knowledge prior to the CHEM 773 course, with the final two teachers sharing positive changes to their chemistry content knowledge.

- “I have had little to no exposure to the concepts taught in this course.” – Teacher 39
- “I've dusted off the old cobwebs and relearned a lot of forgotten material in preparation for teaching AP chemistry next year. I definitely improved my knowledge from every week of this class that includes problem sets, discussions and tests.” – Teacher 45
- “I have learned a lot. I majored in biology for undergrad, so my chemistry knowledge was pretty limited.” – Teacher 40

One teacher discussed knowledge that they gained from fellow teachers in the program through the discussion forums.

- "I actually learned a lot each week from reading other people's [discussion forum] posts." – Teacher 45

Many teachers ($N = 10$) stated that the most meaningful aspects of courses were those that allowed them to practice and solidify their chemistry content knowledge. Some examples of teacher statements are given below.

- "Practicing and applying knowledge is where I feel my biggest gains as a learner." – Teacher 5
- "I found the homework sets and the exam purposeful and allowed me to have more practice with the content." – Teacher 39
- "I think the meaningful aspects of the course are the activities and exercises where we are able to process and really understand the material." – Teacher 36
- CHEM 773 "exposed me to subjects that I have never learned before." – Teacher 42

When discussing how the CHEM 773 course benefitted them, all teachers but one ($N = 14$) discussed improvements to their chemistry content knowledge. A selection of responses is given below.

- "I gained a much better understanding of acid base reactions and equilibrium conditions. I applied the principles of equilibrium to situations that were entirely new to me, such as solubility and phase changes." – Teacher 40
- "I have not used equilibrium equations since college and really needed a refresher." – Teacher 9
- "I have been able to gain a tremendous amount of knowledge of Equilibria and Acid-Base Chemistry from this course." – Teacher 11

- "I learned so much more about equilibrium and was exposed to many more applications than I have encountered in the past." – Teacher 22

Similarly, when discussing the course's value for money, seven teachers mentioned the value of gaining new content knowledge. Some examples of teacher statements are given below.

- "I felt like this course was worth the money since it improved my understanding of the concepts involved." – Teacher 39
- "I feel the topics discussed and the material learned made the cost of the course worth it." – Teacher 14
- "I'm learning a lot." – Teacher 40

When discussing how their chemistry content knowledge had changed during the Spring 2023 semester, most teachers ($N = 12$) mentioned knowledge changes, each of whom described improvements to their chemistry content knowledge. Examples of participant responses are given below.

- "I was able to gain a better understanding of pH, equilibrium, and acid-base." – Teacher 44
- "I have much more knowledge about equilibrium systems, especially the coupling of equilibrium systems." – Teacher 22
- "I can honestly say now that I am much more understanding in equilibrium topics than I ever thought I would be. I didn't realize how much other factors such as common ions or pH played a role in the equilibrium of solutions." – Teacher 38
- "My chemistry knowledge has grown by leaps and bounds this semester." – Teacher 9

In terms of pedagogical skill, several teachers ($N = 6$) discussed gaining knowledge of new teaching strategies and activities as a result of the MS program. Some examples are given below.

- "I have gained many ideas for activities related to equilibrium that I can implement in my classes." – Teacher 22
- "I think I gained enough knowledge to be ready to teach AP chemistry next school year." – Teacher 29
- "I have a wider variety of examples and explanations at my disposal." – Teacher 45

Besides chemistry knowledge and pedagogical skill, teachers also described gaining knowledge of new content and different educational resources.

- "Some ideas of demonstrations and lab activities to make my classes more interesting." – Teacher 40
- "Just a lot of general knowledge, especially relating to equilibrium." – Teacher 45
- "Examples of equilibrium to use in class." – Teacher 14
- "I have also learned I should have referred to ionic compounds as salts this entire time." – Teacher 39

When asked how they had become more effective teachers during the Spring 2023 semester, several teachers pointed to their improved content understanding and KoR.

- "I feel that a stronger understanding of content has made me more effective as a teacher." – Teacher 5
- "Through improving my understanding of the subject matter." – Teacher 39

- “From the knowledge I've gained from my colleagues and professor, I have an ample supply of activities, discussions, and labs that I can include in my chemistry classes to better improve my teaching practice and student engagement.” – Teacher 44
- “Becoming more aware of real-life examples to use.” – Teacher 14

<u>Summary of Knowledge (K-p and K-c)</u>

Through the CHEM 773 course, teachers gained knowledge of chemistry content and teaching strategies. The most common themes for knowledge were:

- The CHEM 773 course allowed teachers to improve their knowledge of equilibria and acid-base chemistry topics, while interactions with fellow teachers allowed for the exchange of teaching ideas and examples of content to use in their own instruction. In the Spring 2023 semester, participants discussed gains in KoSc, KoT, and KoR.
- Improved chemistry content knowledge enabled MS program participants to become more effective teachers, demonstrating improvements to their PCK.
- Chemistry content knowledge gains led participants to rate CHEM 773 highly in terms of course benefit and value for money.

<u>Examples of Skill (S-c)</u>

Several teachers discussed changes to their pedagogical skill after taking CHEM 773. Some felt they were better able to explain the content after participating in the course.

- “The course will help me explain equilibrium concepts to my students.” – Teacher 42

- CHEM 773 “helped me in my explanation of acids and bases in my chemistry classes.” – Teacher 14
- “Being able to better explain concepts related to acid/base and equilibrium” – Teacher 45

Similarly, teachers discussed how their experience in the course gave them ideas for teaching the content more effectively.

- “I have become a more effective teacher because I now have a better idea on how to present material to my students.” – Teacher 11
- “I think I will be better equipped to teach equilibrium and help students relate to it through the use of skills and ideas I have gained this semester.” – Teacher 22
- “I teach the material better than in previous years.” – Teacher 37

One teacher shared how their KoA has been impacted by improvements to their pedagogical skill.

- “I have become more effective because I can ask better questions to assess student understanding.” – Teacher 9

Another teacher found that they began emphasizing problem-solving skills.

- “I think I have a new fondness of problem-solving skills.” – Teacher 38

<u>Summary of Skill (S-c)</u>

Through participation in the CHEM 773 course, several participants ($N = 8$) discussed changes to their pedagogical skill. The main themes for skill were:

- The CHEM 773 course improved teachers’ pedagogical skill by giving them the content knowledge necessary to explain concepts well, which enabled them to improve their overall teaching effectiveness.

- Teachers applied knowledge and skills gained in the MS program to their teaching, which demonstrates the applicability of the courses.

Examples of Teaching (T)

Most teachers ($N = 12$, 80%) discussed how their teaching has been impacted due to their experience in the MS program during the Spring 2023 semester. Many teachers discussed the value of gaining knowledge or resources that they could bring back to their classrooms.

- "Certain aspects were more meaningful to me because I was able to see how I could potentially use them in the future. I would maybe be able to use some of the discussion questions in a class I plan to teach or an idea from the equilibrium paper…I will probably bring up [solving for pH using the quadratic formula] every time my students talk about their math class using it." – Teacher 11
- "The CoRe is something that I can take directly to my classes. The paper/discussions gave good stories to tell my students." – Teacher 4
- "The assignments were applicable to my current classes, and I will be able to implement many of the ideas/lessons…I have already been using what I learned in my classes." – Teacher 22

Some teachers discussed whether or not the CHEM 773 course content was relevant to their current teaching.

- "I don't think [the course content] applied much to what I will be teaching." – Teacher 45
- "Some of [the course content] was very relevant to what I was teaching in my own classes this semester, too." – Teacher 38

- “I don't cover much of what we did for homework for my classes but that may change next year adding college chemistry.” – Teacher 4

Participants shared their main takeaways from the CHEM 773 course, including resources, skills, and knowledge.

- “More deeper level questions and activities in my regular chemistry class.” – Teacher 29
- “I am also going to change the way I teach titrations.” – Teacher 22
- “The discussion forums offer so much insight to techniques other teachers use in their classroom to improve their students learning.” – Teacher 39
- “I have implemented some [lab safety] ideas to make sure the students are less likely to have serious accidents.” – Teacher 40
- “I've found more value in telling stories to gain students interest and help them relate better to the material.” – Teacher 4
- “I have a better idea of where [students] may get stuck or frustrated with the various topics we have discussed in this course.” – Teacher 11

Teachers also descried how they became better teachers through their participation in the CHEM 773 course.

- “The CoRe, equilibrium paper, and discussions made me a better teacher.” – Teacher 44
- “By bringing in a little of what I learned into my own classroom, I think enhances my students' experiences and that they maybe get a little more sense of my passion to teach the subject and that they get energized by this.” – Teacher 38

- "I have become more effective because I can ask better questions to assess student understanding. This is a double edge sword though because I'm also finding that students need more time to learn the concepts." – Teacher 9

Teachers discussed how improvements to their content knowledge and pedagogical skill enabled them to teach CHEM 773 topics.

- "I now have the confidence and maybe even the ambition to teach these concepts that I may have either glossed over or completely skipped because of my deficiencies in knowledge of the content." – Teacher 38
- "I was able to gain a better understanding of pH, equilibrium, and acid-base chemistry what way I can be a better teacher for my students who want to dive deeper into the curriculum…From the knowledge I've gained from my colleagues and professor, I have an ample supply of activities, discussions, and labs that I can include in my chemistry classes to better improve my teaching practice and student engagement." – Teacher 44
- "These examples will help me relate equilibrium to my students." – Teacher 42
- "I think I will be better equipped to teach equilibrium and help students relate to it through the use of skills and ideas I have gained this semester." – Teacher 22

<u>Summary of Teaching (T)</u>

Participants discussed how the CHEM 773 course impacted their teaching. The main themes for this code were:

- Gaining chemistry content knowledge, pedagogical skill, and resources enabled participants to teach their courses more effectively. Their development of KoSc, KoT, and KoR led to improvements in their overall PCK.

- Whether or not CHEM 773 topics were currently relevant to their teaching, participants gained the knowledge and confidence necessary to teach these concepts well.
- Many teachers described student reactions to their instruction or their goals for student learning, therefore demonstrating their KoSt and KoG.

Background (B)

Two teachers shared details of their educational and teaching background, which provides context for their learning experience in the MS program.

- “I majored in biology for undergrad.” – Teacher 40
- “I have not taught an advanced chemistry course.” – Teacher 5

Both teachers described gaps in their experience learning and teaching advanced chemistry concepts, which were remedied through the MS program courses.

Experience (E)

One teacher detailed their learning experience in the program, particularly their experience completing CHEM 773 homework sets.

- “My struggle to learn the material made it so I had to spend more time going through problems to make sure I completely understood what I was doing.” – Teacher 11

Feedback (F)

One of the main purposes of the end-of-semester survey was to collect feedback on the content courses and MS program overall. All participants shared statements coded as feedback, which was sent directly to MS program instructors.

Modules (M)

Four teachers discussed the value of the CoRe assignment as something they can implement in their own classes.

- "CoRe assignment makes me to create a new lesson based on what I learned in this class and then use it in my teaching." – Teacher 29
- "The CoRe is something that I can take directly to my classes." – Teacher 4
- "With the CoRe assignment, it has given me a pathway to implementing a new topic into my curriculum, while thinking about how my students would be able to handle the topic." – Teacher 11
- "I am also going to…use my CoRe assignment for next year." – Teacher 22

One teacher did not find value in the CoRe module, but instead found it stressful.

- "I do not care much to the CoRe assignments. I find them more stressful than meaningful." – Teacher 39

Although feedback on the CoRe was mixed, most teachers found value in creating a lesson on CHEM 773 topics that they could bring into their own classrooms.

Examples of Interaction (I)

Several teachers discussed the value of interacting with other teachers in the discussion forums. Through these discussions, teachers gained new KoT through the exchange of ideas and resources.

- “Being able to bounce ideas, activities, and labs off of each other in the discussions was the most meaningful part of the class to me. It allowed me to teach certain topics in a way, I had never thought of before because I had other teachers to share and develop from.” – Teacher 44
- “Reading the way other teachers explain or approach each topic was great to learn from...I actually learned a lot each week from reading other people’s posts… So many people gave great explanations for difficult concepts in the discussions…I've saved many of these posts in a Google Doc to remind myself in the coming years.” – Teacher 45
- “The discussion forums allowed some interaction with the other students and were a good resource for ideas to use in the classroom.” – Teacher 40
- “I like discussion forums because it helps me ‘talk’ to other teachers and exchange ideas.” – Teacher 29
- “Learning from teachers about what they do give me better ideas of how and what I can teach.” – Teacher 38
- “The discussion forums offer so much insight to techniques other teachers use in their classroom to improve their students learning…Classroom demos that other teachers have shared are very helpful.” – Teacher 39
- “I learn a lot from the other [participants], tips and tricks to make teaching easier.” – Teacher 37

Two teachers also described the value of interacting with instructors for the MS program.

- “The support of professors and advisors has been great!” – Teacher 5

- "The knowledge of the professors and their ability to explain things in a way that we could understand." – Teacher 11

Besides content knowledge and pedagogical skill, teachers gained connections with other science teachers across the nation.

- "Very much enjoyed conversing with other chemistry teachers as I am the only chemistry teacher in my school." – Teacher 42
- "I have been able to make connections with other teachers dealing with similar situations and struggles." – Teacher 22
- "Networking with other teachers." – Teacher 29
- "Connections with other teachers across the nation! How else would I know that teachers all across the country are struggling with teaching after COVID?" – Teacher 9

Summary of Interaction (I)

Through the MS program, teachers were able to interact with each other and SDSU instructors. The main themes for interaction were:

- Through course discussion forums, teachers interacted online through the exchange of ideas, resources, and knowledge. These interactions allowed for the transfer of KoT and KoSc, supporting positive PCK change.
- Participants mentioned the value of having positive interactions with professors who positively impacted their experience in the MS program.
- Teachers formed a supportive community with one another through the MS program, which could potentially extend past the program experience. This

network functioned as a resource for the teachers in the program, especially those who are the only chemistry teacher at their school.

Examples of Reflection (R)

Participants reflected on the CHEM 773 course's benefit and value for money. A selection of responses is given below.

- "I thought almost everything was meaningful to me in some way…It is my first course for this program and my favorite course I've taken for graduate work as a teacher. My strictly education classes from other schools were meaningless and just a way to move up the pay scale." – Teacher 45
- "The course is rigorous and pushes you to better yourself as a learner and a teacher." – Teacher 11
- "I got to have more of in-depth look at equilibrium than I (remember) having before." – Teacher 36
- "Education is always worth money." – Teacher 9
- "I have thought more about what it means to give examples and relate to real-life situations." – Teacher 36

Two teachers discussed the impact of bringing knowledge gained in the MS program into their classrooms. For one teacher, applying knowledge aided them in their own learning. For the other, bringing in new knowledge had a positive impact on their students.

- "I think it really helped that I was able to teach some of this content while in this class that I feel like I was really able to take something out of it…practicing and applying knowledge is where I feel my biggest gains as a learner." – Teacher 5

- “Bringing in a little of what I learned into my own classroom enhances my students' experiences and they maybe get a little more sense of my passion to teach the subject and they get energized by this.” – Teacher 38

One teacher reflected on their own learning preferences.

- “I learn best when I have a person explaining and demonstrating.” – Teacher 9

Some teachers described their interactions with the discussion forum and discussion forum reviews.

- “By the end of the semester, I was very burnt out on discussion posts and it really showed in the quality of my discussion posts.” – Teacher 5
- “I just don't foresee myself going back and read through a discussion review that I have written.” – Teacher 11
- “Discussion reviews…are helpful because I don't go back and read the discussion without this assignment.” – Teacher 9

Teachers reflected on struggles they faced during their experience in the MS program.

- “I often struggle relating topics to students' lives and with the equilibrium topics paper, I now have a whole list of examples I can share with them…I sometimes feel uneasy when teaching topics that are new to me, but now I know I am able to handle difficult topics…It was difficult at times, but I know that my struggle to learn the material has made me develop into a better and more knowledgeable teacher.” – Teacher 11
- “I have struggled more with the workload, fewer hours (5) but more classes (3) than last semester has proved tough.” – Teacher 36

One participant reflected on aspects of their teaching philosophy.

- "As an educator, the most important things for me are making sure my course is relatable and engaging." – Teacher 44

Summary of Reflection (R)

In their responses to the end-of-semester survey, many teachers reflected on their experience in the MS program and how it has impacted their teaching and learning. The main themes for reflection were:

- The CHEM 773 course was beneficial and valuable to participants' teaching and learning.
- Bringing new content knowledge and resources into their classrooms positively impacted participants' KoT and teaching effectiveness.
- Despite struggles teachers faced during their time in the MS program, they gained meaningful KoSc, KoT, and KoR.

Codebook 4

Codebook 4 was used to analyze participants' motivations for statements made in the end-of-semester survey. Coding frequencies can be found in Table 207.

Table 207. End-of-Semester Survey Coding Frequencies for Semester 4 – CB4

Code	**Abbreviation**	**Total Number of Teachers Represented (*N* = 15)**	**Percentage of Total Responses (%)**
Learning-focused	L-f	15	100

Student-focused	S-f	10	66.7
Teaching-focused	T-f	15	100

All participants shared teaching-focused and learning-focused motivations in their responses to the end-of-semester survey. Many teachers also included student-focused (*N* = 10, 66.7%) comments. A selection of teaching-focused statements is given below.

- "As an educator, the most important things for me are making sure my course is relatable and engaging. Being able to bounce ideas, activities, and labs off of each other in the discussions was the most meaningful part of the class to me. It allowed me to teach certain topics in a way, I had never thought of before because I had other teachers to share and develop from." – Teacher 44
- "I feel like I become a stronger teacher every semester." – Teacher 37
- "I have gained many ideas for activities related to equilibrium that I can implement in my classes. I am also going to change the way I teach titrations and use my CoRe assignment for next year." – Teacher 22

All fifteen teachers shared comments related to their own learning that took place in the Spring 2023 semester. Some learning-focused statements are given below.

- "I have gained a deeper knowledge about acids and bases." – Teacher 14
- "I can honestly say now that I am much more understanding in equilibrium topics than I ever thought I would be. I didn't realize how much other factors such as common ions or pH played a role in the equilibrium of solutions." – Teacher 38

- "I have learned a lot. I majored in biology for undergrad, so my chemistry knowledge was pretty limited." – Teacher 40

Two-thirds of participants (*N* = 10) shared comments motivated by their own students' learning. Some examples of student-focused comments are given below.

- "I have become a more effective teacher because I now have a better idea on how to present material to my students. Also, I have a better idea of where they may get stuck or frustrated with the various topics we have discussed in this course." – Teacher 11
- "I've found more value in telling stories to gain students' interest and help them relate better to the material." – Teacher 4
- "By bringing in a little of what I learned into my own classroom, I think enhances my students' experiences and that they maybe get a little more sense of my passion to teach the subject and that they get energized by this." – Teacher 38
- "I have become more effective because I can ask better questions to assess student understanding. This is a double edge sword though because I'm also finding that students need more time to learn the concepts." – Teacher 9

Summary of End-of-Semester Survey

The end-of-semester survey gave teachers an opportunity to reflect on their experience in the MS program during the Spring 2023 semester, especially relating to the CHEM 773 course. All participants shared teaching-focused and learning-focused motivations in their responses to the end-of-semester survey, demonstrating that all teachers gained content and pedagogical knowledge through the CHEM 773 course. A majority of teachers also included statements related to their own students' learning, revealing their KoSt as an aspect of PCK. The main themes from the end-of-semester survey were:

- Through CHEM 773, teachers gained confidence, content knowledge, pedagogical skill, and resources which enabled them to teach more effectively. Gains to their KoT, KoSc, and KoR positively impacted their PCK quantity and quality.
- Teachers were able to reflect on how the content courses have positively impacted their teaching and learning, which provides evidence for the value of the MS program in terms of its participants' PCK and professional development.
- The interactions that take place between the teachers in the MS program enable them to exchange knowledge and ideas, which leads to improvements to their KoSc, KoT, and KoR. In addition to increased PCK, teachers have found a support network in each other, showing another valuable aspect of the MS program. These interactions support teachers' development of PCK, as well as their professional development.

<u>Summary of Semester 4</u>

During Semester 4 of data collection, methods included CHEM 773 discussion forums, the CoRe module and its survey, the post-chemistry content survey, and the end-of-semester survey. The main themes for Semester 4 were:

- Gaining and practicing chemistry content knowledge in the CHEM 773 course through the course requirements, including the discussion forums and the CoRe, allowed teachers to gain confidence in their KoSc and teaching effectiveness. The chemistry content survey revealed how one teacher's chemistry content knowledge increased as a result of MS program courses, which supports qualitative data of teachers' self-perceived content knowledge improvements. By improving their KoSc, the MS program supports improvements to its participants' overall PCK.

- Participants' experience in the MS program during the Spring 2023 semester led to improved PCK through increased KoSc, KoT, KoR, and KoCO. The CoRe provided evidence of teachers' KoG, KoSt, and KoA, as well as the previously mentioned components. The CoRe demonstrated the presence of participants' PCK, but the other data collection methods provided support for the increased quality of their PCK.
- Teachers revealed their application of knowledge and skills from the MS program to their teaching, which demonstrates the MS program's direct impact on participants' instruction. The MS program impacted participants' learning and teaching, which may then have impacted the participants' students' learning.
- Participants expressed value of interacting with fellow teachers in the MS program, leading to increased KoR as a component of teachers' PCK, including the formation of a supportive community of science educators. These interactions supported participants' PCK and professional development.

Summer 2

During the second summer session, program participants took part in a course that involved coming to the SDSU campus for a two-week session. This course, CHEM 776, focused on the development of laboratory activities in conjunction with a laboratory research experience with SDSU research faculty and graduate students. Other courses were also available to the MS participants related to waste disposal, green chemistry, and chemical demonstrations. These courses extended past the on-campus segment; however, the majority of data collection focused on the on-campus experience. Table 208 summarizes the methods used during the summer session.

Table 208. Summer 2 Data Collection Methods

Term	**Data Collection Methods**	**ID Codes**
Summer 2	**Before campus:**	
	ASCI (pre)	ASCI
	Journal #1	SJ
	On campus:	
	Journal #2	SJ
	After campus:	
	Journal #3	SJ
	ASCI (post)	ASCI
	Post-campus summer survey	PCSS
	End-of-summer survey	EOS
	GTA survey	TA

ASCI (pre/post)

Seven participants, excluding the narrative participant, completed both the pre- and post-test of the ASCI. Pre/post data are displayed in Table 209. According to Bauer, the percentage scale indicates the level of the given category that a participant has with respect to Chemistry Laboratory Research, in our case.[64] The categories of attitudes in the inventory include emotional satisfaction, anxiety, intellectual accessibility, interest & utility, and fear.[64] Bauer indicates that a higher score or percentage indicates a higher degree of the attitude; for example, a higher score for anxiety indicates more anxiety and a higher score for emotional satisfaction indicates higher emotional satisfaction.[64]

Table 209. MS Program Participant ASCI Pre/Post Data for Summer 2

Participant Code		Emotional Satisfaction (%)	Anxiety (%)	Intellectual Accessibility (%)	Interest & Utility (%)	Fear (%)
11	Pre	58	47	27	93	50
	Post	58	30	23	97	50
14	Pre	83	17	53	100	0
	Post	75	37	47	87	17
20	Pre	46	63	30	73	67
	Post	46	60	30	70	50
37	Pre	67	47	23	93	33
	Post	58	37	23	90	33
38	Pre	67	43	50	77	17
	Post	54	63	27	63	17
46	Pre	71	33	50	87	17
	Post	92	13	67	100	17
47	Pre	71	43	43	80	33

	Post	67	47	43	100	33

Taking these clarifications into account, we would hope to see an increase in emotional satisfaction, intellectual accessibility, and interest & utility; conversely, we would hope to see a decrease in the teachers' anxiety and fear surrounding chemistry laboratory research.

For emotional satisfaction, four participants experienced a decrease in emotional satisfaction, while one participant became more emotionally satisfied with chemistry laboratory research after the 2-week research experience. Two participants did not experience a change in their emotional satisfaction. A *t*-test indicated that these changes were statistically insignificant ($p = 0.6751$).

In terms of anxiety, four participants experienced less anxiety after the two-week experience, while three participants experienced increased anxiety. A *t*-test indicated that these changes were statistically insignificant ($p = 0.8944$).

For intellectual accessibility, three participants experienced a decrease in intellectual accessibility, while one participant experienced an increase. Three participants did not experience a change in the intellectual accessibility of chemistry laboratory research. A *t*-test indicated that these changes were statistically insignificant ($p = 0.6262$).

In terms of interest & utility of chemistry laboratory research, three teachers experienced an increased in their interest and utility, while four teachers became less interested and found less utility in chemistry laboratory research. Three of these changes were smaller than 5%, demonstrating small changes to participants' interest and utility. A *t*-test indicated that these changes were statistically insignificant (p = 0.9090).

The data for fear indicates that five participants did not experience any changes to their fear. Teacher 20's fear decreased by 17%, whereas Teacher 14 became 17% more fearful of chemistry laboratory research after the summer experience. These results were also statistically insignificant (p = 1.0000).

Summer Journals

Participants involved in the summer session were invited to complete three guided summer journals surrounding their on-campus experience at SDSU. Each of the summer journals was coded using Codebooks 1 and 3, when applicable.

Summer Journal #1

The first journal was prompted prior to teachers arriving on campus and focused on their goals for the experience, both as a teacher and as a scientist, and what they anticipate the experience to be like.

Codebook 1

Coding frequencies for Codebook 1 can be found in Table 210.

Table 210. Summer Journal #1 Coding Frequencies for Summer 2 – CB1

Code	**Abbreviation**	**Total Number of Teachers Represented (*N* = 9)**	**Percentage of Total Responses (%)**
Attitudes	A-p	9	100
Background	B	1	11.1

Goals	G	9	100
Feedback	F	3	33.3
Reflection	R	9	100

<u>Examples of Attitudes (A-p)</u>

Before arrival, teachers shared their attitudes toward coming to campus for the two-week campus research experience. Four teachers shared mixed feelings, including nerves and excitement about the workload and their time in the research labs.

- “I feel nervous because I am not exactly sure what to expect, but I believe it is going to be a great experience. I am excited to learn about the different research that is going on this summer and how I can incorporate the various topics it into my own classroom.” – Teacher 11
- “I am very nervous but excited!” – Teacher 37
- “I'm a little nervous about getting everything done for 4 classes, but I'm sure it'll be okay once there.” – Teacher 46
- “I am excited for this summer, but I'm a little nervous about the lab experience. I was kind of bored when I was in the lab before, so I'm worried that I will be bored again this year.” – Teacher 20

Five teachers discussed feeling nervous or concerned about being in the lab, balancing the workload, interacting with the other MS teachers, and living on campus.

- “I'm a bit nervous about living in a dorm setting again.” – Teacher 20
- “I am concerned about fitting in with the group and the dynamics overall. I'm concerned about being able to balance my courses.” – Teacher 36

- “It is my first summer, so I am a little apprehensive going into the lab as far as my expectations…going back [to a college lab] has been a little intimidating…I'm sure once I'm settled into the dorms and after the first day of lab work that things will be just fine.” – Teacher 38
- “I am prepared to be intimidated at first.” – Teacher 47
- “I am a little nervous about being prepared in either content or skills.” – Teacher 27

Three teachers shared feelings of excitement about being on campus, participating in the research experience, and developing lab skills.

- “I have really enjoyed the course so far, and I am excited that this online course gives the opportunity to travel to campus and further develop lab skills.” – Teacher 47
- “I am excited about the opportunities to learn, grow, and connect in this experience:)” – Teacher 27
- “I am excited to see how it all goes and to be involved with the lab work.” – Teacher 11

Two teachers described their feelings associated with leaving their children to come to campus for two weeks.

- “Personally, I am already homesick because I am leaving my babies for two weeks.” – Teacher 14
- “I have not left my kids for more than two days, let alone two weeks, so this is kind of a big deal for me.” – Teacher 27

Summary of Attitudes (A-p)

All nine teachers shared their attitudes toward coming to the SDSU campus for the two-week research experience, as well as the on-campus portion of the CHEM 776 course. The main themes for attitudes were:

- Teachers expressed feelings of nervousness or apprehension in regard to being in the research lab and interacting with other teachers in the MS program.
- Despite their concerns, teachers also expressed excitement for growth in their lab skills and research knowledge, as well as being on campus.
- Teachers described the personal sacrifices made in regard to being on campus for two weeks, specifically related to family commitments.

Background (B)

One teacher shared their background in terms of lab experience.

- "I haven't been in a college lab situation for almost 30 years now." – Teacher 38

Examples of Goals (G)

In the first journal entry, teachers shared their goals for the summer experience. Several teachers wanted to form connections and learn from other science teachers in the MS program.

- "Build relationships with other science teachers." – Teacher 11
- "I would like to…connect and learn from other teachers." – Teacher 27
- "One of my main goals is to connect with other educators. This was one of the most valuable portions of the on-campus experience I had two summers ago." – Teacher 20
- "Get to know my colleagues better and set up a network with them." – Teacher 38

- "I also want to develop connections with my peers and teachers for potential collaboration." – Teacher 47
- "To create relationships that could benefit my teaching." – Teacher 14

Participants also described their goals for developing lab activities or gaining new lab ideas to bring back to their classrooms.

- "To get some new labs/demos to take back to my classroom." – Teacher 14
- "As a teacher, I am hoping to be able to bring back relevant and innovative labs that are interesting to my students." – Teacher 37
- "As a teacher, I am always looking for new content to bring into the classroom that my students would enjoy and find interesting." – Teacher 38
- "As a teacher, I hope to develop labs/activities I can use inside of my own classroom and enhance my explanations of phenomena students may observe in the classroom." – Teacher 11
- "I also want to develop labs that include feedback from my peers." – Teacher 47
- "New lab and demo ideas." – Teacher 46
- "I hope to gain…more ideas for what labs to do with my students." – Teacher 36

Eight of the nine teachers had goals related to improving their laboratory research skills and learning more about chemistry research.

- "I am hoping to further develop my lab and research skills and…get exposed to current research taking place." – Teacher 37

- “I would like to…gain more experience, confidence, and connection to laboratory work.” – Teacher 27
- “To refresh my memory on various lab techniques and equipment.” – Teacher 14
- “I hope to gain an idea of how real research is done.” – Teacher 46
- “As a scientist, I hope to gain more understanding of the particular type of research happening in the lab I'm working in.” – Teacher 20
- “Develop my lab skills by using equipment I have not used before.” – Teacher 47
- “As a scientist, I would like to relearn lab skills that I have forgotten and perhaps contribute in some small way to help the researcher.” – Teacher 38
- “As a scientist, I hope to learn just a little bit more about the research being done currently and what that looks like… I would like to try to understand, as much as possible, the research being done in my lab.” – Teacher 36

Relating to their laboratory skills, some teachers sought to bring new knowledge of laboratory skills and techniques into their instruction.

- “As a scientist, I hope to gain a better understanding of proper laboratory technique so I can better instruct students.” – Teacher 11
- “I also hope to be able to share my experiences with students.” – Teacher 20

Some teachers demonstrated their KoG by describing their goals to demonstrate how students can use chemistry past high school.

- “I would like to…have exposure to what work in chemistry that is beyond and/or outside of high school so that I can help students see past HS Chemistry.” – Teacher 27

- "In addition, I am looking to gain examples of where students may use science in their daily lives or lives after high school." – Teacher 11

Some teachers also described their goal to become more familiar with SDSU itself.

- "I would like to become familiar with the campus." – Teacher 36
- "I want to explore a different university, and see what a larger university's laboratory looks like, organization, and whatnot." – Teacher 47

Two teachers shared goals for increasing their confidence in the lab.

- "I hope to gain more confidence working in a research facility." – Teacher 20
- "I hope to gain more confidence in doing labs." – Teacher 36

Teachers discussed their goals for reflecting on how they could become better teachers as a result of participating in the summer component of the MS program.

- "I would like to spend regular (2-3 times at least) time reflecting on how my experience and what I've learned and am learning can shape my teaching." – Teacher 36
- "Continue becoming a better and more effective teacher." – Teacher 11

One teacher's comments related to the waste disposal course.

- Learn "how to dispose of many of my chemicals." – Teacher 46

<u>Summary of Goals (G)</u>

Teachers shared their goals for their campus summer experience at SDSU. The main themes for goals were:

- Through participation in CHEM 776 and interactions with fellow teachers, participants hoped to gain new ideas and develop laboratory activities for use in their own classrooms, demonstrating their goal to apply new knowledge and skills to their teaching.

- Teachers hoped to build relationships with other MS program participants while on campus to collaborate professionally and learn from each other.
- By developing lab and research skills, teachers would be able to bring back new knowledge to their students about techniques and the research process. Teachers planned to apply their campus experience to their teaching to benefit their students' learning (KoG).

<u>Feedback (F)</u>

One participant shared feedback in their first journal entry. Data coded as feedback was sent directly to MS program instructors.

<u>Examples of Reflection (R)</u>

Teachers reflected on what the summer campus experience would be like in terms of their expectations.

- "I'm expecting it might be more observations at first and then we will help out. I am hoping it is a friendly environment where learning is appreciated." – Teacher 37
- "I honestly don't know what to expect." – Teacher 11
- "I think we may be mostly observing at first and then hopefully get to help with data collection." – Teacher 46
- "In the lab I anticipate that most of the [graduate students] will have their own projects and depending on the total number of projects/size of the grant they may help each other out or it may be largely independent work. I expect to be

assigned some reading (as of the Thursday before, I haven't been asked to do anything yet) to get up to speed on what is being done in the lab." – Teacher 36

- "I do anticipate, like everything I have encountered so far in this program, that the atmosphere will be relaxed and one of learning." – Teacher 38
- "This is my second summer, though I was not on campus last year. I took a summer off in between campus visits…I met a lot of great people, and I really look forward to meeting more great people again!" – Teacher 20
- "Learning a new job can be stressful! Is this going to be like my first year of teaching: a million new decisions every day? We shall see and I will do my best." – Teacher 27

Two participants reflected on their personal hopes for their summer experience, with the second teacher reflecting on their past summer on campus.

- "I believe I am one of the youngest people enrolled in the course (22) and everyone around me will have years more experience teaching and in chemistry. I hope that the professor I am working with and my partner student are patient with me!" – Teacher 47
- "I am kind of a home body, so this is out of my comfort zone for sure. I guess I am also just hoping the research is easy to understand and that my partner is easy to work with." – Teacher 20

Participants shared various reflective thoughts regarding how they plan to bring knowledge, skills, and feedback they gain on campus back to their classrooms.

- "The more examples I have, the more effective I can be in relating class material to real world examples." – Teacher 11

- "I find [feedback from their peers] very valuable and will definitely use it while I can!" – Teacher 47
- "I think it will be interesting to observe how a research program is going. It will be challenging to adapt that project to a high school lab that varies in equipment and space." – Teacher 14

Summary of Reflection (R)

Teachers shared reflective thoughts on their expectations and hopes for the summer portion of the CHEM 776 course. The main themes for reflection were:

- While most teachers weren't sure what to expect for their time on campus, some anticipated observing graduate students in the lab but hoped to actively participate in and learn from the research process.
- Participants reflected on how they plan to bring knowledge and skills gained on campus back to their teaching.

Codebook 4

Coding frequencies for the first summer journal entry can be found in Table 211 for Codebook 4.

Table 211. Summer Journal #1 Coding Frequencies for Summer 2 – CB4

Code	**Abbreviation**	**Total Number of Teachers Represented (*N* = 9)**	**Percentage of Total Responses (%)**
Learning-focused	L-f	9	100
Student-focused	S-f	5	55.6
Teaching-focused	T-f	6	66.7

All teachers (*N* = 9) shared responses motivated by their own learning, while several teachers also shared teaching-focused (*N* = 6) and student-focused (*N* = 5) motivations. Some examples of learning-focused comments are given below.

- "As a scientist, I hope to learn just a little bit more about the research being done currently and what that looks like." – Teacher 36
- "I am excited to learn about the different research that is going on this summer." – Teacher 11
- "I am hoping to improve lab skills and get exposed to current research taking place." – Teacher 37

Six of the nine teachers discussed what they hoped to gain from their summer campus experience in terms of their teaching. A selection of teaching-focused statements is given below.

- "As a teacher, I hope to develop labs/activities I can use inside of my own classroom and enhance my explanations of phenomena students may observe in the classroom." – Teacher 11
- "It will be challenging to adapt that project to a high school lab that varies in equipment and space." – Teacher 14
- "I hope to gain more confidence in doing labs and more ideas for what labs to do with my students." – Teacher 36

Just over half of the teachers ($N = 5$) gave comments motivated by their own students' learning. Some examples of student-focused statements are given below.

- "I am hoping to be able to bring back relevant and innovative labs that are interesting to my students." – Teacher 37
- "I am always looking for new content to bring into the classroom that my students would enjoy and find interesting." – Teacher 38
- "I hope to gain a better understanding of proper laboratory technique so I can better instruct students. In addition, I am looking to gain examples of where students may use science in their daily lives or lives after high school." – Teacher 11

<u>Summary of Summer Journal #1</u>

In their first journal entry, all nine teachers shared goals for their summer campus experience related to their own learning, while most also included teaching-focused ($N = 6$) and student-focused ($N = 5$) statements. Participants discussed their expectations for their time on campus and in the research labs. The main themes for Journal #1 were:

- Teachers expressed mixed emotions toward coming to campus, including nervousness, apprehension, and excitement to learn new lab skills and research knowledge.
- Teachers' primary goals for the summer campus experience were to gain new lab and research skills, develop laboratory activities to bring back to their teaching, and to build connections with other teachers in the MS program.
- Teachers demonstrated higher quality PCK by sharing their hopes of applying new knowledge and skills to their instruction, which combines their KoSc, KoG, and KoT.

Summer Journal #2

The second summer journal was prompted after the teachers had spent one full week on campus. The journal asked teachers to reflect on their experience in their assigned research lab, as well as the summer courses.

Codebook 1

Coding frequencies are shown in Table 212 for Codebook 1 for the second summer journal entry.

Table 212. Summer Journal #2 Coding Frequencies for Summer 2 – CB1

Code	**Abbreviation**	**Total Number of Teachers Represented (*N* = 11)**	**Percentage of Total Responses (%)**
Attitudes	A-c	10	90.9
Knowledge	K-c	5	45.4

Skill	S-p	1	9.1
	S-c	5	45.4
Experience	E	10	90.9
Background	B	1	9.1
Teaching	T	4	36.4
Feedback	F	8	72.7
Interaction	I	5	45.4
Reflection	R	8	72.7

Examples of Attitudes (A-c)

When reflecting on their first week in an SDSU research lab, several teachers shared positive attitudes about their research experience.

- “I've been thrilled with how much time all three [GTAs] are willing to just be present and answer questions and talk you through things.” – Teacher 2
- “I honestly didn't know what to expect, but I am thankful for the opportunities to learn that have been afforded to me so far!...I am looking forward to finishing the second week strong.” – Teacher 11
- “The lab has been so great!” – Teacher 27
- “I love everything. Honestly, I just feel so thankful for this opportunity. Everyone is wonderful.” – Teacher 37

One teacher discussed the challenge of being in a biochemistry lab that they felt was beyond their level of understanding.

- “The chemistry is a bit above my level of understanding. Biochem is a topic that I do not have much experience with. I am still learning and getting to do some hands-on, but it has been difficult.” – Teacher 38

Two teachers stated that the lab experience exceeded their expectations.

- “It is more and better than what I expected.” – Teacher 47
- “It is so much better than I expected.” – Teacher 37

Two teachers shared attitude changes they have experienced as a result of the summer research experience so far.

- “Builds confidence as a professional and perhaps inspire the next generation.” – Teacher 27
- “The research experience has been meaningful because it has been humbling to be a student learning things for the first time again.” – Teacher 36

Two teachers shared general reflections on the summer campus experience, with both sharing mixed feelings.

- “The days get very long sometimes. It’s a great learning experience, but also very draining.” – Teacher 20
- “It's been great, and it will be hard to see it end.” – Teacher 2

<u>Summary of Attitudes (A-c)</u>

After their first week in the SDSU research labs, most teachers shared positive attitudes about the experience. The main themes for attitudes were:

- Teachers were grateful for the opportunity to learn more about lab techniques, which many planned to bring back to their classrooms.

- Teachers shared that they either weren't sure what to expect about the research experience or that the experience exceeded their expectations.
- One teacher described the difficulty of coming into a research lab with a low level of prior knowledge or experience.

<u>Examples of Knowledge (K-c)</u>

Teachers shared learning outcomes from their first week on campus. Some teachers discussed gaining laboratory knowledge through discussions and being in the research labs.

- "I have learned more about the research process as a scientist and teacher." – Teacher 20
- "So far I have learned how to incorporate more hands-on technology in the chemistry laboratory using Arduinos." – Teacher 47
- "I have accumulated more resources and expanded my laboratory knowledge." – Teacher 47

Teachers also discussed gaining knowledge that could be applied to their teaching of labs.

- "I am learning more about how to better engage and reach my students during the laboratory material of my curriculum." – Teacher 11
- "The morning discussions have been good to build foundational and pedagogical knowledge." – Teacher 6

One teacher generally stated that the learning that has taken place exceeded their expectations.

- "I am learning so much more than I expected." – Teacher 37

Summary of Knowledge (K-c)

Participants described what they had learned during their first week on campus. The main themes for knowledge were:

- Teachers gained laboratory knowledge through the CHEM 776 course, including their experience in the research labs.
- Teachers planned to apply new research and pedagogical knowledge to their laboratory instruction.

Examples of Skill (S-p and S-c)

One teacher described a positive change in laboratory skills as a result of participating in laboratory research at SDSU.

- "I have felt my lab skills were a weakness and I am feeling stronger in this area." – Teacher 37

Teachers shared improvements to their pedagogical skill, particularly related to their instruction of research knowledge and skills.

- "I feel like I could explain research to students better." – Teacher 20
- "I will be better able to convey what research looks like to students…I have gotten better at some skills." – Teacher 27
- "As a teacher [the value of the summer courses] is a different way to apply various techniques I already use with my students." – Teacher 14

Similarly, one teacher described their improved ability to design labs for use in their classroom.

- "This will help me design better low-cost labs." – Teacher 6

One teacher discussed their learning outcomes from the waste disposal class.

- "As a scientist, [the value of the summer courses] is showing how to take those techniques and apply it to chemicals that would be used in industry to replace a harsher chemical." – Teacher 14

Summary of Skill (S-p and S-c)

After their first week on campus, teachers described improving their laboratory and pedagogical skills. CHEM 776, including discussions of educational research and hands-on laboratory research, enabled teachers to apply new techniques in their classrooms related to laboratory instruction.

Examples of Experience (E)

All teachers but one ($N = 10$) related experiences they have had during their first week on campus. Three teachers shared their observations of and reflections on work being carried out in their assigned lab.

- "I like the fact the [GTA] is still using the basics as a major tool for their research. We also will get to see the higher level (expensive*) spectrometers that aren't really feasible in high school chem, but the solubility, molarity calculations, etc. are a great feature to see still being used to describe a chemical compound." – Teacher 43
- "As a scientist, it is very cool to see the science in action. It is enlightening to experience all of the problem solving and cutting-edge techniques used to answer questions we didn't know we had." – Teacher 36
- "The chance to talk through and think through the process of working with ice cores has been so meaningful. I have come to realize that not only is there a lot more going on with the research than I imagined, there is so much innovation still

taking place to make more sense of the vast data that has been gathered in the field overall, but also to come up with new characteristics of the ice that could still be studied if new protocols and connections can be developed. That's science - never ending, just waiting for us to uncover it all." – Teacher 2

Other teachers discussed their own participation in the lab research, including interactions they have had with research professors and GTAs.

- "My research lab experience is going very well! The graduate students are giving us [teachers] freedom to conduct labs related to the research being done in class. The undergraduate researchers are willing to explain, their role and what they are doing. So far, all the researchers within the lab have been very helpful and welcoming." – Teacher 11
- "Our instructors have been really patient and allowed us to try everything while also explaining their work clearly. They each model the task and then we each take turns trying (with guidance)." – Teacher 27
- "I really enjoy being in the physical chemistry lab with [research professor]. It appears that we might be working faster than they expected us to, but the work we do is catered to us." – Teacher 47
- "As a scientist I had time to sit down and play/experiment with ideas I never would have had time or resources for prior." – Teacher 6

Participants then described whether or not the experience had met their expectations.

- "It has been incredible to work in the [research lab]. I would say that it has far exceeded my expectations. Last year I worked on my own with [previous research professor] in their lab, which was great. But to have three others working in the lab with me this year in addition to [GTAs and current research professor], it's been endlessly stimulating.” – Teacher 2

- “It isn’t fully what I expected. The research is very interesting, but our lab experience hasn’t been very hands on.” – Teacher 20
- “I expected to be doing observations but so much of what we are doing is hands-on. We have quickly become part of the lab community. I love how much we are learning and they conversations we are having as well.” – Teacher 37
- “Being assigned to a research lab is incredibly eye-opening…It is more or less what I expected since I've been fortunate enough to spend a summer in a research lab before.” – Teacher 36

Teachers discussed their plans to bring back new ideas and techniques from both the research lab itself and their own development of new lab activities.

- “It is an applicable experience. A lot of what is being tested in the lab I can take back to my own classroom. That was actual surprising to me.” – Teacher 14
- “I have been developing labs from my experience to help take back to school with me.” – Teacher 11

Similarly, one teacher reflected on the integration of research and education in the CHEM 776 course.

- “I like the fact that we are doing so many different activities that help bring together the education and the research.” – Teacher 43

One teacher shared feeling exhausted from the workload but motivated to continue due to the value of the experience.

- "There has been more than enough to do, and being in my second year, the work on finishing my paper and presentation has been exhausting. But every day when it's so hard to wake up after burning the midnight oil again, I think about the sequence of events that will start with our 8am discussion and continue through the day again, and I am motivated to get up and get back to work." – Teacher 2

Summary of Experience (E)

Teachers discussed experiences they have had on campus during their first week, including details of their time in the research labs and reflections on aspects they hope to bring back to their classrooms. The main themes for the experience code were:

- Teachers shared experiences from their assigned research labs, including techniques and aspects of the research process they observed or performed. Participants also discussed their interactions with the GTAs and research professors who guided them through the research experience.
- Teachers had mixed feelings for whether or not the campus experience has met their expectations. Three teachers explicitly described positive shifts compared to their expectations, while one teacher expressed their lab experience not being as "hands on" as they expected.
- Teachers valued the integration of scientific research and education in the CHEM 776 course, which allowed them to consider changes they would make to their own teaching.

Background (B)

One teacher shared how their research background related to their assigned SDSU research lab.

- "This is something I did research on in my undergrad and I am glad I'm getting more experience with it." – Teacher 47

Examples of Teaching (T)

Relating to their knowledge and skills gains, teachers discussed how they planned to bring new ideas and resources back to their students.

- "I also feel like I have so much to bring back to my students." – Teacher 37
- "There are a lot of labs we've done that I would do in my classroom." – Teacher 20

For one teacher, CHEM 776 had an impact on their confidence teaching labs.

- "This summer course has widened the scope of labs that I feel confident in doing with my students." – Teacher 47

Another teacher described gaining more resources for their teaching that would impact both their lecture and laboratory instruction.

- "As a teacher, I have gained many more labs and activities that I can incorporate into my classroom…[The summer courses] have helped me to grow as a teacher, in both my approach to my lecture and laboratory material." – Teacher 11

Summary of Teaching (T)

Teachers planned to bring back laboratory resources, knowledge, and skills to their teaching. The summer component of the MS program had a direct impact on teachers' plans for their future laboratory instruction.

Feedback (F)

Eight participants shared feedback in their second journal entry, which was sent directly to MS program instructors.

Examples of Interaction (I)

Teachers discussed the value of collaborating with fellow MS program participants in person.

- "The summer courses have been meaningful, especially being on campus, because of all of the collaboration." – Teacher 36
- "I have enjoyed getting to…do labs with my colleagues in the program." – Teacher 37

Multiple teachers emphasized the value of living in the dorms with their fellow teachers, stating that this arrangement strengthened their relationships and allowed them to continue discussions after the scheduled workday.

- "The dorm component has been going well. We have all somewhat bonded being together." – Teacher 38
- "The group has been great to network with and discuss things at great length informally back in the dorms, too." – Teacher 2
- "I really like the camaraderie that was discussed. Being in a college dorm after MANY years has been a fun experience. We are all able to continue discussions about the day and our school years because we are not all separated by housing issues at the end of the day." – Teacher 43

Summary of Interaction (I)

Teachers found value in networking with other MS program participants, both during CHEM 776 discussions and in the dorms.

Examples of Reflection (R)

Teachers reflected on their first week in the SDSU research labs. Two teachers reflected on the research experience, with one making connections to the content they teach.

- “This is something that I knew, but could see and hear firsthand as instructors and lab techs recounted their experiences learning to handle mice, dissect corneas, mount tissues, etc. Also, you don’t have to love mice to be able to work with them to get data.” – Teacher 27
- “I like the idea of being able to see that some research (DES investigations) uses so much of what we actually teach in regular chemistry classes in school. pH, density. So many times we are told that the density stuff is basic and that we need to go straight into the higher level thinking, but I still use it for a basic review/teaching method for my physics/biology students. Density is a prime indicator of a substance. Phase as well.” – Teacher 43

Focusing on the CHEM 777 course, two teachers reflected on how the summer experience impacted their action research project.

- “It's been good. Days are awfully long though although I've gotten some good insight from my professors and colleagues on ideas of how to carry out my research.” – Teacher 38
- “I think like so many others (students especially) that having a deadline for small, incremental parts makes it seem like a doable assignment instead of something you would avoid and therefore avoid the whole program for the sake of skipping the dreaded ‘thesis/dissertation’ component of a research program.” – Teacher 43

Three teachers discussed bringing their experiences back to their classrooms.

- "I have enjoyed getting to learn in person…I can't wait to bring back what I learned to the classroom." – Teacher 37
- "I did not think I would be able to take back as much useful lab technique and information as I am able to…The ideas and resources being shared will benefit me in my classroom this next year and years to come." – Teacher 14
- "There have been so many opportunities to think about how I can take the things we're working on and discussing back to my students, even though we clearly don't have access at my school to ice cores or too much of the equipment that we're using." – Teacher 2

One of these teachers also reflected on how they brought aspects of the previous summer into their classroom and had not yet seen an impact.

- "I wonder if I'm just not seeing the payoff from it yet for this year, as I did the video approach last year and it just didn't bear the fruit of curiosity that I had hoped for in my students last year. I will hold on and keep at it in the hope that it will pay off more this year!" – Teacher 2

Two teachers shared reflective thoughts on how the summer component of the MS program impacted their goals and approach toward teaching.

- "I think teachers need to be learners, need to remember what it is to be a student, in order to communicate well to our classes." – Teacher 36
- "I have been reading a variety of articles that have helped me to rethink my approach to my students and my teaching itself." – Teacher 11

Another teacher discussed their reassurance that they are preparing their students well for college.

- "It is good to know that my job of getting students ready for college can be validated by the things people are seeing as teachers at the college level and that the concepts I teach them will also make them readily able to walk into an undergraduate research position and still be a positive contributor to the lab from the first day." – Teacher 43

Summary of Reflection (R)

Many teachers used the summer journal as an opportunity to reflect on their experience on campus so far. The main themes for reflection were:

- Teachers reflected on their experience in the research labs, making connections to their own curricula.
- Participants stated that the CHEM 777/788 component of the summer experience enabled them to make progress on their action research projects.
- Several teachers discussed how they plan to bring ideas and experiences from the campus research experience back to their classrooms. The CHEM 776 course, including the research experience, impacted how teachers approached laboratory instruction.

Codebook 4

Codebook 4 then allowed me to break down the teacher statements by source of motivation. Each comment was assessed to determine the focus of the comment, either focused on the participant's learning, their students' learning, or the participant's teaching. Coding frequencies are displayed in Table 213.

Table 213. Summer Journal #2 Coding Frequencies for Summer 2 – CB4

Code	**Abbreviation**	**Total Number of Teachers Represented (N = 11)**	**Percentage of Total Responses (%)**
Learning-focused	L-f	11	100
Student-focused	S-f	6	54.5
Teaching-focused	T-f	10	90.9

All teachers (N = 11) shared responses focused on their own learning motivations and all teachers but one (N = 10) shared statements motivated by their own teaching. Just over half of the participants shared student-focused (N = 6) motivations. Some examples of learning-focused comments are given below.

- "The research experience has been meaningful because it has been humbling to be a student learning things for the first time again." – Teacher 36
- "The morning discussions have been good to build foundational and pedagogical knowledge." – Teacher 6
- "I am learning so much. I have enjoyed getting to learn in person and do labs with my colleagues in the program." – Teacher 37

Most teachers discussed what they will take away from the summer campus experience related to their own teaching. A selection of teacher statements is given below.

- “It is an applicable experience. A lot of what is being tested in the lab I can take back to my own classroom. That was actual surprising to me. I did not think I would be able to take back as much useful lab technique and information as I am able too.” – Teacher 14
- “As a teacher, I have gained many more labs and activities that I can incorporate into my classroom.” – Teacher 11
- “There have been so many opportunities to think about how I can take the things we're working on and discussing back to my students, even though we clearly don't have access at my school to ice cores or too much of the equipment that we're using.” – Teacher 2

Over half of the participants discussed how their learning on campus could impact their own students’ learning. Some student-focused comments are given below.

- “I will better be able to convey what research looks like to students and perhaps inspire the next generation.” – Teacher 27
- “It is good to know that my job of getting students ready for college can be validated by the things people are seeing as teachers at the college level and that the concepts I teach them will also make them readily able to walk into an undergraduate research position and still be a positive contributor to the lab from the first day.” – Teacher 43
- “I am learning more about how to better engage and reach my students during the laboratory material of my curriculum.” – Teacher 11

Summary of Summer Journal #2

In the second journal entry, all teachers shared learning-focused motivations, while all but one ($N = 10$) gave responses motivated by their teaching. Many participants ($N = 6$) discussed the potential impact their summer experience could have on their own students' learning. The main themes from teachers' second journal entries were:

- During their first week on campus, teachers learned new lab knowledge and techniques (KoSc) that they planned to bring back to their classrooms (KoT). By combining these knowledge bases, teachers demonstrated improvements to their PCK quality. Teachers hoped to apply new research and pedagogical knowledge to their lab instruction. The summer component of the MS program provided teachers with new skills and knowledge that positively impacted their PCK.
- Teachers detailed interactions they had on campus, including lab instruction from GTAs and SDSU faculty, chemical education discussions with MS program instructors and participants, and continued discussions with fellow teachers in the dorms. These interactions allowed for professional networking, which participants felt would extend past their summer research experience. These interactions enabled teachers to experience PCK and professional development.
- Teachers were also able to make progress on their action research projects through the CHEM 777/788 courses.

Summer Journal #3

The third and final journal entry was prompted after participants had completed their two weeks on the SDSU campus. The prompting questions asked the teachers to reflect on what they have gained through their experience, such as professional development, networking opportunities, and other takeaways. Teachers were also asked to share their thoughts on the summer session, including if their expectations were met, how the on-campus experience went overall, and any other final thoughts on the two-week session.

Codebook 1

Coding frequencies from Codebook 1 are shown in Table 214.

Table 214. Summer Journal #3 Coding Frequencies for Summer 2 – CB1

Code	**Abbreviation**	**Total Number of Teachers Represented (*N* = 8)**	**Percentage of Total Responses (%)**
Attitudes	A-p	1	12.5
	A-c	6	75
Knowledge	K-c	7	87.5
Skill	S-p	1	12.5
	S-c	2	25
Goals	G	7	87.5
Background	B	1	12.5
Experience	E	5	62.5

Teaching	T	8	100
Feedback	F	6	75
Interaction	I	8	100
Reflection	R	7	87.5

Attitudes (A-p and A-c)

Teachers primarily shared positive attitudes related to their two weeks on campus. Two teachers shared new attitudes they have taken away from the summer experience, including improved lab skills, a greater respect for laboratory research, and increased teaching motivation.

- "I took away more confidence in my lab skills and a profound appreciation for the research taking place." – Teacher 37
- "My takeaway as a scientist would be the importance of lab work…This experience has helped to ramp up my drive to become a better teacher." – Teacher 11

One teacher shared mixed feelings about their experience, but related positive learning outcomes in terms of their K-c.

- "I really enjoyed the two weeks. They were stressful, but I learned a lot and have a lot to take back to my classroom." – Teacher 20

Another teacher discussed feeling nervous prior to arrival, but shared positive attitudes when reflecting on their experience.

- "To be completely honest, I was very nervous arriving to campus. Going into this program I felt that I wasn't 'enough' of a teacher. I mean, I haven't even began teaching yet! I didn't think I would be able to keep up with everyone else that has years of experience. I am happy to say that everyone made me feel like I had a right to be there with them. I cannot wait to come back next summer." – Teacher 47

Other teachers also expressed positive attitudes toward the two weeks on campus, stating that they enjoyed their experience, looked forward to coming back, and/or would miss not coming.

- "I loved the whole two weeks." – Teacher 46
- "I am so grateful for this first summer of experience. It was great and I can't wait to come back next year…I feel I have grown so much." – Teacher 37
- "I am just thankful for the program!...I am excited that I still have one more summer." – Teacher 11
- "I enjoyed it a lot. I am going to miss not going next year." – Teacher 14

<u>Summary of Attitudes (A-p and A-c)</u>

Teachers mostly shared positive attitudes toward the summer campus experience. The main themes for attitudes were:

- Teachers shared positive attitudes toward what they took away from the experience, including improved confidence in their lab skills, increased teaching motivation, and a greater appreciation for laboratory research.
- In general, teachers enjoyed the on-campus portion of CHEM 776. Teachers possessed positive attitudes toward the summer component of the MS program, stating that they looked forward to their second summer or would miss not returning.

Knowledge (K-c)

Teachers discussed learning from fellow chemistry teachers, GTAs, and research faculty while on campus.

- "I have learned more about how professors, teachers, and graduate students work at the professional level." – Teacher 47
- "I learned so much, not just from the lab group I was in, but from everyone else in the program." – Teacher 47
- "I have learned a lot about how other chemistry teachers teach and the curriculum they use. I have also learned a lot about how to introduce lab experiences in my classroom." – Teacher 20

Teachers also discussed knowledge gains related to the research process.

- "I definitely have a better understanding of what research is." – Teacher 46
- "As a scientist, I learned of research opportunities and learned a few new techniques." – Teacher 38
- "I was able to…learn more about research." – Teacher 20

In their third journal entry, two teachers discussed the general learning that took place while on campus.

- "I have…expanded my knowledge immensely." – Teacher 37
- "I learned so much." – Teacher 14

Summary of Knowledge (K-c)

Teachers discussed knowledge gains they experienced through the two-week campus experience. The main themes for teachers' current knowledge were:

- Teachers discussed gaining knowledge through interactions with fellow MS program participants, GTAs, and SDSU faculty.
- Teachers gained a better understanding of the chemistry laboratory research process.

Skill (S-p and S-c)

Two teachers discussed changes to their skill resulting from their summer campus experience. The first teacher discussed gaining pedagogical skill in terms of laboratory development, showing an impact of the CHEM 776 course.

- "I always struggled to [find] good, well thought out labs that would make the students think critically. The labs and hands-on activities we all made are going to help aid me in choosing and making better labs for my students." – Teacher 11

The second teacher described growth to their laboratory skills, including techniques that they'd hoped to improve.

- "I wanted to grow my lab skills and that definitely happened. I got to practice so many techniques that I've previously wanted to get better at like micro pipetting and extractions." – Teacher 37

Goals (G)

Six teachers stated that they met their goals for the campus experience, while one teacher described not meeting goals due to a lack of expectation for the experience. Some examples are given below.

- "I grew professionally and the time I spent with [research professor] was beyond my expectations." – Teacher 47

- "I wanted to get to do labs and activities while in the grad student lab, and I did." – Teacher 46
- "I'm not sure that I met any personal goals as I really didn't know what to expect." – Teacher 38

Background (B)

One teacher shared details about their background. Their first comments related to their appreciation for getting to interact with other chemistry teachers due to the lack of chemistry teachers at their school.

- "At home in my teaching job I have to work alone as I don't share any content areas with any of my co-workers at my site…I very rarely get to spend time with other chemistry educated teachers. So many come from other science backgrounds that the conversation generally wanders away from chem." – Teacher 43

They also shared details of their teaching context compared to what they heard from other MS participants.

- "I might have large class sizes in [state], but I don't have to teach more than two preps, maybe three per year." – Teacher 43

Experience (E)

In their third journal entry, teachers reflected on experiences that occurred while on campus. Some teachers detailed their experience in an SDSU research lab.

- "I really liked [research professor's] lab. We got to experience a little bit of the research they are doing." – Teacher 46

- “I learned so much, had fun, and worked on things I was very interested in.” – Teacher 47
- “In terms of the research experience, I was partly expecting to watch the graduate students perform their labs so when we completed a lab on the first day, I was surprised. It was a good surprise though; it was a great experience overall.” – Teacher 11

One teacher described their experience in the lab not meeting expectations due to the lack of active participation.

- “I did complete all the requirements for my classes which was important. The research experience did not meet my expectations, but maybe because my expectations were too high. I did get a chance to do a few things on my own such as grow my own cell cultures, but for the most part, it was a lot of watching others do their work in a field I knew very little of.” – Teacher 38

One teacher discussed their experience making progress on their action research project.

- “I was able to get my action research stuff finished and ready for this fall.” – Teacher 11

Another teacher discussed their experience applying knowledge gained in the waste disposal course.

- “The waste class was very helpful. In fact, in [research professor’s] lab, if we used chemicals that could be disposed of down the drain, I got to do it. Like I neutralized some sulfuric acid so it could be poured down the drain.” – Teacher 46

Unrelated to the content of the MS program, a teacher discussed the logistics of their time on campus.

- "This was my first summer and for the most part the experience was very pleasant. Checking in and out of the dorms was very easily done. The dorms themselves were pretty comfortable besides the mattresses. Everyone chipped in to create dinners most nights there." – Teacher 38

Finally, one teacher compared their first and second campus experiences, remarking on a change to the CHEM 776 course.

- "I was here the summer of 2021, and we didn't do the lab experience with Instructor A in the afternoon." – Teacher 20

Summary of Experience (E)

Teachers discussed their experiences on campus, including their involvement in the research labs, the action research course, and the waste disposal course. Teachers also reflected on the logistics of being on campus, comparisons between two iterations of CHEM 776, and how the experience failed to meet expectations.

Teaching (T)

All eight teachers described gaining new ideas to bring into their teaching, demonstrating improved PCK. Some examples of teacher statements are given below.

- "As a teacher, I took many ideas that I can hopefully incorporate into my classroom." – Teacher 38
- "I have more ideas about labs and demos to use in class." – Teacher 46

- “This summer has shown me that there is still a lot of chemistry information that I don't know. I was always learning new things throughout the summer experience and it has given me ideas for my own classroom.” – Teacher 11
- Some takeaways from the summer research experience were “the amount of resources and how to adapt various activities in my classroom.” – Teacher 14

Teachers described what they took away from the summer research experience both as a teacher. Some examples of teaching takeaways are given below.

- “As a teacher it is the reassurance of how I am doing things and support in adapting material.” – Teacher 14
- “I found of lot of the labs [discussed in CHEM 776] to be something I would use in my classroom.” – Teacher 20
- “I like the lab development and feel that I can incorporate several into my teaching. Since they come from a different perspective, I think I can add to the expectations of my district that we not only cover chemistry but some earth science as well, in the classroom…I am glad to know I am still up on all of the tools and applications of chemistry and what students need to know to be useful in an undergraduate type lab assignment.” – Teacher 43

Summary of Teaching (T)

Through the two-week campus experience, teachers gained knowledge, skills, and ideas that they planned to incorporate into their teaching. The main themes for teaching were:

- Teachers took away new resources, including laboratory ideas and activities, that they plan to use in their own classrooms. Their increased KoR indicated improved PCK.
- Teachers reflected on how they can incorporate new ideas and experiences from the summer experience into their teaching.

<u>Feedback (F)</u>

Six of the eight participants shared feedback in their final journal entry, which was sent directly to MS program instructors.

<u>Interaction (I)</u>

When reflecting on their summer experience, teachers shared networking opportunities that had arisen through being on campus. Several teachers described making new connections with fellow teachers, SDSU faculty, and GTAs.

- "Made many great professional connections and grew my network significantly." – Teacher 38
- "I have made great connections with other colleagues. I've connected with other teachers but also grad students and professors." – Teacher 37
- "I was able to meet and make connections with some great people." – Teacher 20

Teachers also discussed using these connections for future collaboration or support.

- "To collaborate and develop potential collaborations in the future." – Teacher 38
- "I have met a ton of wonderful educators that I can reach out to for support and collaboration."- Teacher 20
- "I feel I can reach out to [SDSU faculty and staff] for assistance and they would be happy to help me." – Teacher 47

Participants described their desire to connect with fellow MS participants at professional conferences in the future.

- "I have connected with teachers from around the US and one even in my same state. I am excited to keep in touch and hopefully run into some folks at conferences." – Teacher 47
- "I've recruited at least one teacher to join [state] Association of Teachers of Science and hopefully a few in the area will come to NSTA in Kansas City in the fall. It was wonderful to see everyone in person and get more acquainted with my classmates." – Teacher 46
- "I have been able to connect with science teachers from across the country along with some professors and faculty from SDSU. Also, there were discussions about science conferences that can be attended, which was interesting!" – Teacher 11

Teachers reflected on how and what they learned from each other while on campus.

- "A ton [of networking opportunities have arisen through being on campus]!! There were group chats, emails, and virtual folders that we have access to material…I had a great time talking with everyone and learning from each other." – Teacher 14
- "I have been able to work with colleagues to see through lab development…I enjoyed spending time with the people I only see on Zoom. Our experiences of the past helped to shape who we are and how we teach. Spending time with each other and finding out the path that led us all to the same place (SDSU) was very helpful." – Teacher 43

Teachers described what they have taken away from these interactions, emphasizing the impact of collaborating with other chemistry teachers.

- "My biggest takeaway is that I am not in this alone. I have a lot of support, and I feel better knowing that there are common problems most science/chemistry teachers face." – Teacher 47
- "It has been nice to see how others around the country have the same happiness and troubles…It is good to spend time with so many others with the same educational background… having a whole group of chemistry majors was helpful to interact with" – Teacher 43

Summary of Interaction (I)

Participants emphasized the value of connecting with fellow teachers, SDSU faculty, and GTAs while on campus and described utilizing these connections in the future. The main themes for interaction were:

- Teachers grew their professional network through the summer campus experience, stating their desire to utilize these connections in the future.
- Teachers shared their desire to connect with MS program participants at conferences in the future, indicating that these connections may serve as motivation for professional development.
- Teachers felt supported through their collaboration with other chemistry educators, describing the value of the MS program uniting science teachers from across the country.

Reflection (R)

One teacher reflected on the value of connecting with other chemistry teachers on campus in terms of learning about different teaching contexts.

- “You can get so isolated in your classroom that you rarely have time to talk to colleagues at your own site. I also find it interesting that there are so many other courses being offered that we do not at home, but the downside is that so many other teachers in rural areas are stuck with so many preps that it must be difficult to complete a full day without being exhausted. Knowing that other schools are running on different time frames and expectations is new to me.” – Teacher 43

Teachers described what they took away from the summer research experience as a scientist Some examples of takeaways are given below.

- “As a scientist, I learned that it is okay to fail, take a second to be upset, but pick your head back up and keep working to find an answer.” – Teacher 47
- “As a scientist it is a fresh look on how to approach material.” – Teacher 14
- “As a scientist, I have learned that research takes a lot of time. It can be very frustrating and rewarding. Research is also not quite as complicated as I initially thought.” – Teacher 20
- The summer research experience “made me wish I would've tried to do more [lab work] when I was completing my undergrad.” – Teacher 11

Teachers also reflected on the campus experience as a whole. Some examples are given below.

- “There was enough downtime to enjoy everyone's company and not too overloading. There was a variety of experiences that everyone had the opportunity to take home valuable lessons.” – Teacher 14
- “I really enjoyed my time on campus for the first summer.” – Teacher 43
- “I loved how hands on the experience was.” – Teacher 37
- “It was wonderful. I loved all the things. I had a great experience… It was nice to be a college student again, but I've been I am glad to be home” – Teacher 46

One teacher reflected on the value of the summer component of the MS program.

- “I understand why some of the people in their 2nd year said this is the best part of the whole program.” – Teacher 11

Summary of Reflection (R)

Teachers reflected on their two-week campus experience, focusing on the following themes:

- Teachers’ experiences in the lab allowed them to reflect on how they approach teaching chemistry, including their thoughts on chemistry research.
- Participants reflected on the summer component of the program, highlighting its value.

Codebook 4

Codebook 4 then allowed me to break down the teacher statements by source of motivation. Each comment was assessed to determine the focus of the comment, either focused on the participant’s learning, their students’ learning, or the participant’s teaching. Coding frequencies are displayed in Table 215.

Table 215. Summer Journal #3 Coding Frequencies for Summer 2 – CB4

Code	**Abbreviation**	**Total Number of Teachers Represented (N = 8)**	**Percentage of Total Responses (%)**
Learning-focused	L-f	8	100
Student-focused	S-f	2	25
Teaching-focused	T-f	8	100

All eight teachers shared responses motivated by their own learning and teaching, while two teachers gave statements related to student-focused motivations. A selection of learning-focused statements is given below.

- "This summer has shown me that there is still a lot of chemistry information that I don't know. I was always learning new things throughout the summer experience." – Teacher 11
- "As a scientist, I learned that it is okay to fail, take a second to be upset, but pick your head back up and keep working to find an answer." – Teacher 47
- "As a scientist, I have learned that research takes a lot of time. It can be very frustrating and rewarding." – Teacher 20

All participants discussed what they learned through the summer campus experience that applied to their own teaching. Some examples of teaching-focused comments are given below.

- “This experience has helped to ramp up my drive to become a better teacher.” – Teacher 11
- “As a teacher, I took many ideas that I can hopefully incorporate into my classroom.” – Teacher 38
- “I found a lot of the labs to be something I would use in my classroom.” – Teacher 20

Two teachers (25%) related their experiences to potential impacts on their own students’ learning. These examples are given below.

- “I am glad to know I am still up on all of the tools and applications of chemistry and what students need to know to be useful in an undergraduate type lab assignment.” – Teacher 43
- “I always struggled to [find] good, well thought out labs that would make the students think critically. The labs and hands-on activities we all made are going to help aid me in choosing and making better labs for my students.” – Teacher 11

<u>Summary of Summer Journal #3</u>

The third journal entry allowed all teachers ($N = 8$) to reflect on their teaching- and learning-focused motivations, while only two teachers discussed potential impacts on their students’ learning. Most teachers met their goals for the two-week campus experience. The main themes for the third summer journal were:

- Teachers gained laboratory development skills and teaching ideas that they planned to incorporate into their curricula, demonstrating improved PCK through increased KoR, KoCO, and KoT.

- Participants improved their knowledge of the laboratory research process and gained practical laboratory skills through their experiences in the SDSU research labs. By improving their KoSc, teachers displayed improved PCK.
- Teachers possessed positive attitudes toward the summer component of the MS program and described positive outcomes related to their confidence and motivation. Participants emphasized the value of the summer campus research experience.
- While on campus, teachers formed or strengthened connections with fellow MS program participants, SDSU faculty, and GTAs. Many teachers also showed interest in reconnecting at conferences, showing increased motivation for professional development due to their involvement in the MS program. These interactions supported teachers' PCK and professional development.

Post-Campus Summer Survey

After the conclusion of the two-week on-campus session, participants were invited to complete a survey about their time on campus. Teachers discussed the most and least beneficial aspects of the two-week experience, how their view of the research process has or has not been impacted by their time in SDSU research labs, and if they plan to change the laboratory work they do with their students as a result of their experience in CHEM 776.

<u>*Codebook 1*</u>

Coding frequencies are presented in Table 216 for Codebook 1 for the post-campus summer survey.

Table 216. Post-Campus Summer Survey Coding Frequencies for Summer 2 – CB1

Code	**Abbreviation**	**Total Number of Teachers Represented (N = 10)**	**Percentage of Total Responses (%)**
Attitudes	A-c	3	30
Knowledge	K-c	1	10
Skill	S-c	2	20
Background	B	1	10
Experience	E	1	10
Teaching	T	10	100
Feedback	F	10	100
Interaction	I	5	50
Reflection	R	7	70

Attitudes (A-c) and Skill (S-c)

Two teachers discussed attitudes resulting from gaining waste disposal skills.

- "The most beneficial was the hands-on experience from the waste disposal class. I have more confidence that I know how to dispose of chemicals safely." – Teacher 40
- "The waste class [was the most beneficial]. Now I have actually experienced the disposal methods and feel very confident going into my lab and disposing of a few chemicals I have." – Teacher 46

One teacher described how their previous summer in the CHEM 776 course gave them the confidence to use these labs in their classroom.

- "Having an opportunity to test these labs gave me confidence in using them in my classroom." – Teacher 20

Knowledge (K-c)

One teacher described gaining knowledge from the CHEM 776 discussions.

- "I learned so much from the group discussions in the morning." – Teacher 47

Experience (E)

One teacher described their experience with the GTAs in their lab, particularly relating to what they learned from them about research and instrumentation.

- "The conversations with the [GTAs] in the lab were powerful; I was amazed everyday with how much time they were willing to give us in terms of just talking about the science, the tools, their experiences in the field and lab, the instrumentation involved in their work, and in answering the questions we always seemed to have. It wasn't a one-way lecture on their part but a conversation that was always framed around a more questioning approach to helping us reach a more complete understanding of the concepts of the research." – Teacher 2

Teaching (T)

Teachers shared the value of gaining ideas and activities in CHEM 776 to bring back to their classrooms.

- CHEM 776 discussions and labs "helped give me ideas on activities to perform with my students." – Teacher 14

- "It was amazing to…be able to bring stories/experiences back for our students!" – Teacher 37
- "Going through the labs, I have gained ideas for how I could incorporate something similar into my own curriculum." – Teacher 11

One teacher described how improved waste disposal skills will impact the materials they use in their lab instruction.

- Gaining waste disposal skills "will allow me to expand the range of chemicals that we work with in my classroom." – Teacher 40

Most participants had plans to bring new knowledge, skills, or resources from the summer experience into their teaching. Several teachers discussed using the lab activities discussed, developed, and performed in the CHEM 776 course. They also described how these labs fill gaps in their current curriculum or serve as replacements for existing materials.

- "I plan on using some of the labs that we did together and some of the hands-on activities were fun and new, but mostly were engaging for students." – Teacher 38
- "I plan to do some of the labs we developed in class this year… as well as some of the labs that the other teams developed. I am always looking for new lab ideas, and there were some really good ones presented as part of the 776 class." – Teacher 40
- "I am glad that I'll have access to the other labs that groups developed, and I can look back on them for reference." – Teacher 47
- "I plan on utilizing as many of the labs as possible. I also have ideas on how to redo some of the labs I already use in class." – Teacher 14

- “I will definitely have some real-life experiences that I can use to relate the value of certain concepts to the class. I also plan to use the resources myself and others made during the time on campus.” – Teacher 37
- “There were a lot of great ideas for labs from the ones developed this year by my cohort group as well as the ones from the articles chosen by Instructor A for our consideration, so those will definitely find their way into my classes' lab experience. There are some labs that fill a gap I've had in my curriculum, and some that are better ways of experiencing a concept than what I've had in the past.” – Teacher 2

One teacher shared concrete plans for using the lab they developed in the coming school year.

- “I already have the lab I developed using Arduinos in my lab schedule for the year.” – Teacher 47

When discussing bringing activities from CHEM 776 into their teaching, some teachers demonstrated their KoG – thus indicating their PCK – by planning to integrate more real-world examples.

- “I like the integration of chem and earth science from acid rain and volcanic activity using pH and ion concentrations. I plan to use both in class and share with AP Enviro students.” – Teacher 43
- “I am going to use my experience to help relate more of the material I am teaching to the students and how it can affect them. I have gained more examples of how science is used in everyday life, which I believe will help the students to understand the importance of why they need to learn it!” – Teacher 11

- “I will incorporate more technology in my labs. I also want to include more local/real world lab activities. The microplastics and acid rain labs really prompted this decision, although the area I'm in is rural and not prone to a lot of pollution, it would still be interesting!” – Teacher 47
- “I want to do the oil of wintergreen lab, just so my students can experience a tiny bit, the process of making cancer drugs.” – Teacher 46

Teachers reiterated their plans for future teaching by discussing changes they would make to their lab instruction. Three teachers hoped to shift toward a more inquiry-based approach for labs. Their comments demonstrated their KoG and KoT by focusing on creating better learning experiences to serve their students in the future.

- “I am going to move toward more inquiry style labs thanks to my experience in 776. I found participating in the inquiry labs to be more interesting and better learning experiences. I believe this will be better for my students. I will also be incorporating the ‘next question" at the end of my labs.’ – Teacher 37
- “I am going to try and incorporate more inquiry and critical thinking into my labs. Let the kids explore trial and error and not just give them a super detailed outline/procedure to follow. In class, we discussed inquiry-based learning with labs because it allowed students a bit more freedom to try certain things within the lab and come to their own conclusions.” – Teacher 11
- “I plan to change how I introduce some of my labs. I like the idea of having a more inquiry-based approach. I also plan to use more technology as the school is able to afford it. I think this will better prepare my students for college chemistry.” – Teacher 20

Participants shared a variety of changes they would make to the structure of their labs.

- "I think adding more unknown components, evidence support sections, and having students create their own lab techniques." – Teacher 14
- "I would like to add more background to labs. I don't know if students would read the background, but I did like some of the materials presented on the last few days." – Teacher 43

One returning teacher discussed how they have brought new knowledge and skills from their previous summer into their teaching.

- "Some of the articles we discussed and then explored in the lab (afternoons) during my first year were great additions to my own classes. The experiences in the lab with [research professor] during my first summer were really transferrable to the conversation in my own classes, both AP Chemistry and regular Chemistry classes, in various places throughout the year." – Teacher 2

Two teachers have used the labs or activities developed in a previous summer on campus, one of whom described their experience implementing their activities into their curriculum.

- "The hands-on activity from my 2022 experience was pretty relatable and worthwhile for my own classes; my lab activity from 2022 wasn't all that successful in the 'beta testing' environment, and I just didn't take the time last year to fine tune in while trying to carry out my research, etc., in the program. I hope to revisit it this coming year." – Teacher 2

Summary of Teaching (T)

Teachers discussed how they plan to integrate ideas and resources from the CHEM 776 course into their teaching. The main themes for teaching were:

- Teachers improved their KoR by gaining ideas and activities from the CHEM 776 course, including labs they developed themselves. These resources filled gaps in teachers' curricula or allowed them to improve existing activities.
- Many teachers planned to utilize lab activities that were inquiry-based or had real-world connections, demonstrating teachers' KoG and KoT as components of their PCK.
- Returning teachers implemented labs developed in CHEM 776 into their instruction, demonstrating the impact of the MS program on participants' teaching.
- Teachers gained knowledge and skills through the waste disposal elective course, which enabled them to expand their use of chemicals in their instruction.

Feedback (F)

All ten participants shared feedback in the post-campus summer survey, which was sent directly to MS program instructors

Interaction (I)

When reflecting on their two-week campus experience, several teachers described the impact of interacting with fellow MS program participants. Two teachers emphasized the value of creating a professional network of teachers that they could utilize in the future.

- "The most beneficial part of the experience was the network that we were able to create throughout the two weeks together. The network will allow me to communicate and share ideas or help each other as we go back to school and try to implement things that we took away from the experience." – Teacher 38
- "I think the most beneficial part was networking with the other teachers. I made some great connections that will allow me to collaborate for many years to come." – Teacher 20

Others discussed the benefit of exchanging labs they developed in CHEM 776 with other science teachers.

- "The most beneficial was all the labs ran and discussed ideas with like-minded individuals." – Teacher 14
- "Journal discussions, reviewing others' lab products. Gave us a chance to see other work and get us to view different perspectives on a lab we might have already known." – Teacher 43

One teacher discussed the positive impact of interacting with those in their research lab at SDSU.

- "The time in the lab with [research professor and GTAs] (along with my cohort group) was really impactful." – Teacher 2

<u>Summary of Interaction (I)</u>

Teachers discussed the value of interacting with other science teachers, SDSU faculty, and GTAs while on the SDSU campus. Teachers formed a professional network that they planned to use beyond their time in the MS program. They also found value in gaining new perspectives on lab instruction from their peers.

Reflection (R)

Teachers reflected on their experience on campus. One teacher connected to their background by describing the benefit of having past experience with equipment used in their assigned research lab.

- "Overall, I think I benefitted most from being in a lab that I was really interested in and already had experience working with the electronics." – Teacher 47

One teacher described the benefit of observing research at SDSU.

- "The most beneficial part of the two-week experience was the time in the research lab. It was amazing to see research up close." – Teacher 37

Another teacher expressed the benefit of gaining new resources (KoR) through the CHEM 776 course that could be used in their classroom.

- "For me, the labs and hands-on activities are the most beneficial. I have struggled with finding or making high quality labs/activities, and through this experience I have been exposed to making better labs/activities for my students." – Teacher 11

Finally, a returning teacher reflected on how they were better prepared for their second summer on campus based on prior experiences.

- "I was able to pull more information into discussions because I'd worked with another cohort of people before. I also was more familiar with the research and expectations for me." – Teacher 20

Summary of Reflection (R)

Teachers reflected on the most beneficial aspects of their summer campus experience, including participating in laboratory research, gaining new instructional resources, and applying prior knowledge to their discussions and research in CHEM 776.

Codebook 4

Coding frequencies for the post-campus summer survey for Codebook 4 are given in Table 217.

Table 217. Post-Campus Summer Survey Coding Frequencies for Summer 2 – CB4

Code	**Abbreviation**	**Total Number of Teachers Represented (*N* = 10)**	**Percentage of Total Responses (%)**
Learning-focused	L-f	10	100
Student-focused	S-f	7	70
Teaching-focused	T-f	10	100

All ten teachers shared comments motivated by their own learning and teaching, with most participants (*N* = 7) also including statements related to student-focused motivations. A selection of learning-focused statements is given below.

- "I learned so much from the group discussions in the morning." – Teacher 47
- "The lab research was also biochemistry, concentrating on DNA electrophoresis…It was beneficial, and I learned a lot." – Teacher 40
- "I learn best by doing things rather than discussing." – Teacher 37

Many of the questions in the post-campus summer survey asked teachers to describe if and how they planned to bring any aspects of the summer campus experience back into their classrooms. Some examples of teaching-focused comments are given below.

- "There were a lot of great ideas for labs from the ones developed this year by my cohort group as well as the ones from the articles chosen by Instructor A for our consideration, so those will definitely find their way into my classes' lab experience. There are some labs that fill a gap I've had in my curriculum, and some that are better ways of experiencing a concept than what I've had in the past." – Teacher 2
- "I plan to change how I introduce some of my labs. I like the idea of having a more inquiry-based approach." – Teacher 20
- "I will incorporate more technology in my labs. I also want to include more local/real world lab activities. The microplastics and acid rain labs really prompted this decision, although the area I'm in is rural and not prone to a lot of pollution, it would still be interesting!" – Teacher 47

The majority of teachers also reflected on how they would apply knowledge gained from the MS program to benefit their students' learning. A selection of student-focused statements is given below.

- "I am going to use my experience to help relate more of the material I am teaching to the students and how it can affect them. I have gained more examples of how science is used in everyday life, which I believe will help the students to understand the importance of why they need to learn it!" – Teacher 11

- "I also plan to use more technology as the school is able to afford it. I think this will better prepare my students for college chemistry." – Teacher 20
- "I want to do the oil of wintergreen lab, just so my students can experience a tiny bit, the process of making cancer drugs." – Teacher 46

Summary of Post-Campus Summer Survey

In their responses to the post-campus summer survey, teachers described the impact of the experience on their future instruction. All ten teachers included comments related to learning- and teaching-focused motivations, with most also including responses motivated by their own students' learning ($N = 7$). The main themes from the post-campus summer survey were:

- Teachers gained knowledge, skills, and resources from the CHEM 776 and waste disposal courses. Therefore, the summer courses for the MS program impacted participants' KoR and KoT, indicating improved PCK.
- Teachers planned to integrate new lab activities into their instruction, which improved or filled gaps in their existing curricula. Gaining KoR and KoCO demonstrated teachers' improved PCK. Practicing labs in CHEM 776 enabled teachers to feel more confident using these lab activities in their classrooms.
- Teachers demonstrated their KoG and KoR as a component of their PCK by planning to implement activities that were inquiry-based or contained real-world connections, which demonstrated their desire to engage students in their own learning.

- Participants formed a professional support network with each other that they plan to utilize beyond their time in the MS program. Interactions among MS program participants supported PCK and professional development.
- Returning teachers had implemented labs developed in CHEM 776 into their instruction, demonstrating the impact of the MS program on participants' teaching effectiveness, professional development, and PCK growth.

End-of-Summer Survey

The end-of-summer survey follows the same format as the other end-of-semester surveys and focuses on what knowledge and skills teachers gained from these courses, along with feedback that participants have shared. The end-of-summer survey was analyzed using Codebooks 1 and 4.

Codebook 1

Coding frequencies for the end-of-summer survey can be found in Table 218 for Codebook 1.

Table 218. End-of-Summer Survey Coding Frequencies for Summer 2 – CB1

Code	**Abbreviation**	**Total Number of Teachers Represented (N = 8)**	**Percentage of Total Responses (%)**
Attitudes	A-p	1	12.5
	A-c	3	37.5
Knowledge	K-c	6	75
Skill	S-c	6	75

Experience	E	4	50
Teaching	T	4	50
Feedback	F	8	100
Interaction	I	7	87.5
Reflection	R	5	62.5

Attitudes (A-p and A-c)

Three teachers shared attitude changes resulting from the summer campus experience. One teacher reflected on feeling nervous beforehand but came out with a positive perception of the two-week experience.

- "The experience I had on campus this summer exceeded my expectations. I was nervous coming into it, but it turned out to be a great time." – Teacher 11

When reflecting on what they had gained from the summer component of the MS program, another teacher mentioned gains from a student's perspective.

- "I also would say a renewed sense of patience and collaboration - becoming the student for 2 weeks instead of the teacher." – Teacher 25

A third teacher discussed gaining confidence in their skills and feeling inspired to improve their teaching as a result of the summer campus experience.

- "I feel challenged to be a better teacher from both a pedagogical and informational point of view. This is a result of being surrounded by teachers and professors who are doing a wonderful job!...I feel more confident in my skills…I have grown so much and feel I've fallen more in love with this craft!" – Teacher 37

Knowledge (K-c)

Teachers discussed knowledge that they gained during their two weeks on campus. Some participants learned from other MS program participants and SDSU instructors.

- “I learned a lot from the other teachers.” – Teacher 37
- “I learned a lot about teaching from Instructor A and the other teachers in the program.” – Teacher 20

Teachers primarily described gaining chemistry content knowledge through their participation in the SDSU research labs.

- “My content knowledge has increased because of the research I observed this summer. I was exposed to a number of different lab related things and cross disciplinary aspects of chemistry, biology, computer coding, and pharmacology.” – Teacher 11
- “I grew in the areas of biochemistry and organic chemistry thanks to the research experience. I also feel I learned a lot about green chemistry, environmental chemistry and some inorganic too thanks to the labs we did… I learned so much in the research lab.” – Teacher 37
- “I learned a little more about how some of the ‘alphabet soup’ fancy instruments work.” – Teacher 46
- “Either as a teacher or learner, I found some parts to be more meaningful because I was broadening my knowledge and understanding of a topic…[their chemistry content knowledge] has been refined and I have a better idea on some of the topics that were discussed.” – Teacher 25

One participant stated that they did not experience any changes to their KoSc.

- “I did not gain a whole lot of chemistry content knowledge.” – Teacher 20

Teachers also described gaining knowledge, including new KoR, from CHEM 776, as well as the waste disposal and demonstrations courses.

- “I wouldn't say I learned anything new, but I definitely have an idea of possible new labs that I can do or ways to teach topics based on discussions, etc.” – Teacher 25
- “I gained many new resources!” – Teacher 37
- “I have some new demos I can use and waste techniques, and I definitely know a little more about how research works so I can share it with my students.” – Teacher 46

Participants noted improvements to their pedagogical skill through the CHEM 776 discussions.

- “I gained knowledge to better my teaching skills.” – Teacher 14
- “I learned some new motivational and inquiry approaches. For example, we learned about using badges for motivation and utilizing a next question to drive student interest.” – Teacher 37
- “I've learned some different pedagogical techniques such as using the VR, prompting discussions with a demonstration, and finding a place for inquiry.” – Teacher 20

Summary of Knowledge (K-c)

Teachers discussed changes to their knowledge resulting from the summer campus experience. The main themes for knowledge were:

- Teachers gained knowledge through interactions with other MS program participants and SDSU faculty.
- Most teachers described gaining chemistry content knowledge through the summer research experience, demonstrating improved PCK through increased KoSc.
- Teachers gained new resources (KoR) during their two weeks on campus, indicating improvements to their PCK.
- Teachers also gained new pedagogical knowledge through the CHEM 776 discussions.

Skill (S-c)

Participants discussed skills they developed through the summer campus experience. Many teachers discussed improvements to their pedagogical skill, particularly related to laboratory development and their approach to laboratory instruction.

- "I have learned how to better accommodate my lab for all students." – Teacher 20
- "I'm also reminded that it's important to foster a safe, positive environment for students so they are comfortable working with each other." – Teacher 25
- "776 helped me growth my laboratory design and implementation skills." – Teacher 37

One teacher also demonstrated their KoG by expressing their desire to highlight the relevance of science to students' everyday lives.

- “I have gained insight on how I can provide better more meaningful labs to my students, along with providing them with more examples of how science is related to their lives.” – Teacher 11

Teachers also described additional pedagogical gains.

- “My ability to explain and teach [chemical] information has increased.” – Teacher 20
- “I hope I am more efficient in designing my curriculum.” – Teacher 14
- “I've also gained a better insight in how to run group discussions.” – Teacher 25

One teacher discussed gaining skills related to the waste disposal course.

- “I'm going to dispose of some chemicals the right way.” – Teacher 46

Another teacher reflected on additional skill gains resulting from their two-week campus experience.

- “I learned a lot of personal skill and personal preference in potential graduate research.” – Teacher 25

<u>Summary of Skill (S-c)</u>

Teachers discussed developing skills through the summer campus experience, especially related to laboratory development. The main themes for skill were:

- Teachers took away improved skills for creating more meaningful lab experiences for their students. They discussed creating a more accommodating laboratory environment and improving their laboratory design. These comments related to teachers’ KoG and KoSt.
- Teachers also gained additional pedagogical skill related to curriculum design and instruction, demonstrating improvements to their KoCO and KoT.

Participants' skillsets indicated improved PCK.

Experience (E)

Three teachers shared experiences they had while on campus. The first teacher related that the research experience exceeded their expectations. They also discussed applying new waste disposal skills in their assigned research lab.

- "I was hoping to get to do a few things, but we had experiments or activities to do every day we were there…I got to use some waste techniques in [research professor's] lab. Like we used a little sulfuric acid in one lab and [the GTA] said they would take care of it, but I wanted the 'practice,' so I became the waste person for a few days." – Teacher 46

Another teacher described experiences from both CHEM 776 and CHEM 788, reflecting on the essence of each course.

- CHEM 776 "also allowed me to experience a research lab and why their work is vital. 788 was helping me finish up my own research. The feedback given from the course allows me to correct any mistakes I made in my presentation and paper." – Teacher 14

The third teacher reflected on their experience on campus in terms of preparing for their action research project and gaining KoR through the CHEM 776 discussions.

- "I was given time to prepare for my research and data collection in the fall all while gathering more labs and activities to bring into my classroom." – Teacher 11

Teaching (T)

Teachers related their summer campus experience to their teaching. Teachers discussed developing and learning about new resources through the MS program, including lab activities and demonstrations, that they planned to bring into their own classrooms. The summer courses improved participants' KoCO and KoR, thus improving their PCK.

- "The laboratory development [course] helped give new labs and demonstrations to do with my class… Both [CHEM 776 and CHEM 788] gave a good amount or resources, feedback, and labs to use for future use in my classroom." – Teacher 14
- "The aspects of this program that were very meaningful to me were things that I am going to take back to my classroom and use…I am definitely going to use the activities and labs [from CHEM 776] in my classroom!" – Teacher 11
- "The program also motivated me to take the reins and develop a meaningful lab I will use in my classroom." – Teacher 47
- "I have more labs and activities that I know work for the most part that I can use throughout the year and didn't stress over making all of them. I also have new ideas concerning electronic assignments." – Teacher 25

One teacher reflected that the courses had a positive impact on their teaching effectiveness.

- "Both of the courses I took were beneficial because they helped to prepare me for this fall and helped me to become a better and more effective teacher!" – Teacher 11

Another teacher shared a change to their teaching approach in terms of laboratory expectations.

- Their pedagogical skill "changed in the aspect of my expectations for my students in lab." – Teacher 14

Summary of Teaching (T)

Through the summer campus experience, teachers gained KoCO and KoR through new lab activities and demonstrations that they plan to bring into their own classrooms. Teachers also described improved teaching effectiveness and changes to their teaching approach. Therefore, the summer component of the program supported positive PCK changes and had a direct impact on participants' teaching.

Feedback (F)

All eight participants shared feedback in the end-of-summer survey, which was sent directly to MS program instructors.

Interaction (I)

Teachers discussed interactions that took place while on campus. Some teachers described opportunities for interaction with other teachers in MS program summer courses.

- During CHEM 776 discussions, "I love being in the big circle and hearing from everyone." – Teacher 46
- "I like 788's collaborative and helpfulness in just listening to other presentations and commiserating over common issues from the research project." – Teacher 25

All teachers but one (*N* = 7) described new connections they gained through the summer campus experience that they plan to utilize for future collaboration or support. Some examples of teacher statements are given below.

- "I was able to build some great connections and relationships with other awesome science teachers." – Teacher 11
- "Connections to other chemistry teachers who have different teaching styles, student populations, etc." – Teacher 25
- "I have gained a lot of friends that also teach science. I can bounce ideas off of them to improve as a teacher." – Teacher 20
- "A network of individuals to ask questions if I need ideas or help." – Teacher 14
- "Learned a lot about collaboration and extending my professional network to include those in the program." – Teacher 38

Teachers also reflected on the value of the community that was formed on campus.

- "I loved the sense of community and bonding that took place. It's definitely exhausting, but I enjoyed talking to everyone and learning about everyone's experience in teaching chemistry…I'm trying to adjust my teaching style to college level, so it was interesting to talking to others who also teach college chemistry." – Teacher 25
- "The community…exceeds my expectations." – Teacher 37

<u>Summary of Interaction (I)</u>

Teachers described connections they formed while on campus. Seven of the eight teachers discussed building new relationships with other MS program participants, which they planned to utilize for collaboration or support in the future. Teachers also emphasized the value of forming a community of science teachers during the summer campus experience. Interacting with fellow teachers in the MS program had both professional and personal impact on participants.

Reflection (R)

Teachers reflected on the value of various aspects of the CHEM 776, especially in terms of what they could take away from the course as teachers.

- "I rated the courses I took 6 because they were very beneficial to me and my development as a teacher going through this master's program…The discussions were good, and they make me think, but I may not go back and reference those things when I am teaching." – Teacher 11
- "Most of the program was meaningful to me. I value anything that helps me grow as a teacher or learner." – Teacher 37
- "I am much more willing to try a new activity in class if I know it works well." – Teacher 20

One teacher reflected on their overall experience in summer MS program courses.

- "I think overall, [CHEM 776] is a great course for just meeting other teachers, learning from others, and experiencing something unique…I think I did more in [CHEM 788] than any other semester." – Teacher 25

Other teachers also discussed what they gained from the summer experience, including knowledge, practical experience, and interactions.

- "The experience I had, knowledge I gained, and relationships I formed are well worth the money in my opinion." – Teacher 20

- "The research experience exceeds my expectations…I got great hands-on experience!" – Teacher 37
- "The labs we completed in the classroom exceeded my expectations." – Teacher 14

One teacher discussed improvements to their pedagogical skill, which demonstrated their KoG as a component of their PCK.

- "This summer has given me guidance on how I can better communicate labs with my students, along with how I can better relate it to their everyday lives." – Teacher 11

Another teacher reflected that they cannot determine changes to their pedagogical skill until they return to teaching.

- "I am unsure since I am not in my classroom yet." – Teacher 14

To conclude, a teacher reflected on the value of their general experience in the MS program.

- "It is hard to believe that I am over halfway finished with the program! The material doesn't come easy, but it is definitely worth the time and money! I have had a great experience so far!" – Teacher 11

<u>Summary of Reflection (R)</u>

Teachers reflected on their experience in summer MS program courses, particularly related to what they gained from their time on campus. The main themes for reflection were:

- Aspects of the CHEM 776 course allowed for teachers' professional development by giving them opportunities to learn and practice new skills and activities.

- The two-week campus session provided teachers with valuable experiences that exceeded their expectations.
- Although teachers gained new knowledge and resources, they may not be able to determine impacts on their instruction until they return to their classrooms.

Codebook 4

Coding frequencies for the end-of-summer survey can be found in Table 219 for Codebook 4.

Table 219. End-of-Summer Survey Coding Frequencies for Summer 2 – CB4

Code	**Abbreviation**	**Total Number of Teachers Represented (*N* = 8)**	**Percentage of Total Responses (%)**
Learning-focused	L-f	8	100
Student-focused	S-f	3	37.5
Teaching-focused	T-f	7	87.5

All eight teachers shared comments motivated by their own learning, with most participants ($N = 7$) also including statements related to teaching-focused motivations. Fewer than half of the teachers ($N = 3$) discussed student-focused motivations. A selection of learning-focused statements is given below.

- "I found some parts to be more meaningful because I was broadening my knowledge and understanding of a topic." – Teacher 25

- "My content knowledge has increased because of the research I observed this summer. I was exposed to a number of different lab related things and cross disciplinary aspects of chemistry, biology, computer coding, and pharmacology." – Teacher 11
- "I grew in the areas of biochemistry and organic chemistry thanks to the research experience. I also feel I learned a lot about green chemistry, environmental chemistry and some inorganic too thanks to the labs we did." – Teacher 37

The end-of-summer survey allowed teachers to reflect on how the Summer 2023 term had impacted their teaching. Some examples of teaching-focused comments are given below.

- "The program also motivated me to take the reins and develop a meaningful lab I will use in my classroom." – Teacher 47
- "I feel challenged to be a better teacher from both a pedagogical and informational point of view." – Teacher 37
- "My ability to explain and teach the information has increased." – Teacher 20

Three of the teachers gave responses motivated by their own students' learning. These examples are provided below.

- "This summer has given me guidance on how I can better communicate labs with my students, along with how I can better relate it to their everyday lives." – Teacher 11
- "I'm also reminded that it's important to foster a safe, positive environment for students so they are comfortable working with each other." – Teacher 25
- "I have learned how to better accommodate my lab for all students." – Teacher 20

<u>Summary of End-of-Summer Survey</u>

The end-of-summer survey allowed teachers to reflect on their experience in MS program summer courses, particularly during the two-week campus session. All eight teachers included comments related to learning-focused motivations, with most ($N = 7$) also including responses motivated by their teaching. Three teachers reflected on how the summer campus experience may impact their own students' learning. The main themes from the end-of-summer survey were:

- The summer campus experience equipped teachers with laboratory knowledge and skills and inspired them to make changes to their own approaches to laboratory instruction. These improvements to teachers' KoSc were applied to their KoT, which demonstrated improved PCK quality.
- Teachers gained new KoCO, KoT, and KoR through their two-week campus experience that they planned to incorporate into their instruction, demonstrating a direct impact of the CHEM 776 course on participants' teaching. These knowledge gains also indicated improvements to their PCK.
- Teachers gained new professional and personal connections with other MS program participants that they planned to utilize in the future for support and collaboration. These connections supported teachers' PCK and professional development.
- Teachers gained chemistry content knowledge (KoSc) during their experience in the SDSU research labs, demonstrating another improvement to participants' PCK.

- In addition to CHEM 776, teachers described the impact of making progress toward their action research projects and gaining knowledge of waste disposal techniques, which improved their KoSc as a component of their PCK.

Through their summer campus experience, teachers experienced professional development which led to improved PCK.

GTA Survey

Graduate teaching assistants (GTAs) from the Department of Chemistry & Biochemistry worked with the MS program participants in the research labs. In order to understand how the two-week experience went from a mentoring perspective, a post-survey was given to GTAs following their work with the teachers. One GTA – designated as GTA 5 – responded to the survey and reflected on their first summer working with the teachers. Table 220 displays frequencies of each code's appearance in the dataset.

Table 220. GTA Survey Coding Frequencies for Summer 2 – CB1

Code	**Abbreviation**	**Frequency of Responses (*N* = 15)**	**Percentage of Total Responses (%)**
Attitudes	A-c	5	33.3
Skill	S-c	2	13.3
Goals	G	1	6.7
Feedback	F	2	13.3
Experience	E	1	6.7
Reflection	R	3	20

Attitudes (A-c)

In terms of current attitudes, the first-time GTA expressed positive attitudes toward their experience working with the MS teachers.

- “I had a good time working with the teachers.”
- “I appreciate the opportunity to work alongside these teachers.”
- “It was a great experience working alongside the teachers.”

GTA 5 expressed appreciation for the opportunity to share their research and expressed interest in working with the teachers again in the future.

- “Working with the teachers was a great experience and I won't mind doing it in the future. I have always appreciated the opportunity of sharing my research and passion with others.”

GTA 5 had a positive reaction in terms of the teachers’ attitudes during their time in the research lab.

- “The teachers were more enthusiastic and curious which was a pleasant surprise for me.”

GTA 5 expressed overall positive attitudes toward working with the MS participants.

Skill (S-c)

In terms of skills, GTA 5 first described skills that the MS participants practiced in their lab.

- “The teachers learned the basics behind the more 'complicated' protocols that we perform in the lab.”

GTA 5 then described skills they developed through the experience in terms of scientific communication.

- "Through this process, I have been able to learn how to explain procedure/protocols differently to allow others outside the field to understand the purpose and the goal of the experiment.

The summer campus research experience allowed both MS participants and GTAs to develop skills.

Goals (G)

GTA 5 described their goal for the summer experience and expressed their achievement of this goal.

- "My goal was to help the teachers through one of the procedures done routinely in the lab and we were able to successfully complete it."

GTA 5 was able to guide the participants through procedures in the research lab.

Feedback (F)

GTA 5 provided two comments coded as feedback. These comments were sent directly to MS program instructors.

Experience (E)

GTA 5 described the MS teachers' experience in their research lab.

- "They got to perform a lot of those protocols under supervision and also got first-hand experience of working in a research lab."

Reflection (R)

GTA 5 shared three comments reflecting on the two-week research experience with the MS teachers. They first reflected on the teachers' behavior.

- "They were inclined to learn and were curious about the different procedures and asked questions."

GTA 5 reflected on their expectations prior to working with the MS teachers.

- "Since I have been a TA before for freshmen college students, I expected this experience to be similar."

GTA 5 then described their experience with the teachers and reflected on the teachers' experience in the research lab.

- "This experience was different than my teaching experiences from the past… they were thorough with some of the basic concepts that made it easier for them to understand the purpose for doing different experiments."

Summary of GTA Survey

GTA 5 responded to the GTA survey and described their first summer working with the MS teachers. The main themes from their responses were:

- GTA 5 enjoyed their experience working with the MS teachers and appreciated the opportunity to share their research with the teachers, showing the value of the summer research for the GTAs as well as the MS program participants.
- GTA 5 confirmed MS participants' evaluation of their research experience from an observer's perspective by describing the teachers' positive attitudes and behaviors toward working in the research labs.
- GTA 5 described skills that the MS teachers gained during the research experience (KoSc), which supports the value of the summer component of the MS program in terms of helping teachers develop PCK and experience professional growth.

<u>Summary of Summer 2</u>

During the second summer session, methods included the ASCI (pre/post), three summer journal entries, a post-campus summer survey, and the end-of-summer survey. Teachers experienced professional development through their two-week session on the SDSU campus. The main themes for Summer 2 were:

- Teachers did not experience statistically significant changes in their attitudes toward chemistry laboratory research after participating in an SDSU research lab.
- Although teachers expressed mixed emotions toward coming to campus, the two-week experience allowed participants to meet goals related to gaining laboratory knowledge, skills, and confidence that could translate to their teaching. Teachers gained KoSc, KoT, and KoR, which improved their overall PCK.
- Teachers planned to bring new laboratory approaches and resources into their teaching, demonstrating a direct impact of the MS program on its participants' instruction. Participants emphasized the value of performing labs on campus, stating that practicing the activities beforehand gave them the confidence to use them in their own classrooms. Bringing in new activities revealed improvements to teachers' KoR and KoCO as components of their overall PCK.
- Teachers planned to implement an inquiry-based approach or incorporating real-world connections into their lab instruction, demonstrating their KoG as a component of their PCK.
- Participants who took the waste disposal elective course gained new skills that would enable them to incorporate a wider range of materials in their classrooms. Similarly, teachers who participated in the demonstrations course gained KoSc

and KoR to be applied to their instruction, which indicated improved PCK quality.

- Returning teachers stated that they had implemented labs developed in a previous iteration of CHEM 776, showing participants' active integration of KoR gained in the MS program. This also reveals the summer campus experience's impact on teachers' PCK and professional development.
- Teachers developed relationships with each other, GTAs, and SDSU faculty that will extend past their time in the MS program. Teachers demonstrated the value of forming a support network through which they can collaborate in the future. These interactions supported teachers' PCK and professional development.
- Participants also made progress on their action research projects, which are a requirement for the MS degree. Preparing and executing their action research for the MS program enabled teachers to gain knowledge and skills to pursue action research in their classrooms in the future.
- Teachers emphasized the value of the summer component of the MS program.

Alumni

Alumni Survey

In Fall 2022, I sent out a survey to alumni for the program to gather information about the lasting impact of the MS program on its participants. Seventeen alumni replied, with participants from as early as the Fall 2014 semester extending to Summer 2022. They were asked to discuss professional, pedagogical, or personal changes they experienced due to their participation in the MS program. They also reflected on their overall experience in the MS program and provided feedback for how it could be improved for the future. The Alumni Survey was analyzed using Codebooks 1 and 3. Data coded as feedback was further analyzed using Codebook 3.

Codebook 1

Coding frequencies from Codebook 1 can be found in Table 221 below.

Table 221. Alumni Survey Coding Frequencies – CB1

Code	**Abbreviation**	**Total Number of Alumni Represented (N = 17)**	**Percentage of Total Responses (%)**
Attitudes	A-p	7	41.2
	A-c	14	82.4
Knowledge	K-p	5	29.4
	K-c	11	64.7
Skill	S-p	9	52.9
	S-c	4	23.5
Background	B	6	35.3
Experience	E	1	5.9
Feedback	F	17	100
Teaching	T	12	70.6
Interaction	I	4	23.5
Reflection	R	15	88.2

Teacher Descriptions

Alumni were first asked to describe themselves as teachers before they entered the MS program and currently.

Attitudes (A-p and A-c)

Some alumni respondents described themselves solely in terms of their attitudes toward teaching, including their teaching confidence.

- Alum 2 discussed improved confidence as a chemistry teacher, indicating professional development through the MS program.
    - Prior: “I was a decent teacher, but I didn't feel extremely confident in my chemistry content knowledge and laboratory safety skills.”
    - Current: “I am more confident as a chemistry teacher.”
- Alum 4 felt more confident in their chemistry content knowledge, which demonstrated improved PCK through increased KoSc.
    - Prior: “I was a good teacher, but there were areas of my curriculum where I did not feel confident.”
    - Current: “I am better organized and much more confident in my content.”
- Alum 6 gained maturity through the MS program, which indicates professional development that occurred through the MS program.
    - Prior: “Inquisitive, motivated, caring, naïve”
    - Current: “Inquisitive, motivated, caring, mature”

<u>Knowledge (K-p and K-c)</u>

- Alum 8 described themselves as a teacher in terms of their content knowledge. They described improvements to their KoSc, which demonstrated improved PCK.
    - Prior: "Okay, but definitely needed a reminder on some content."
    - Current: "Much more knowledgeable."

<u>Skill (S-c)</u>

- Alum 9 discussed their current teaching in terms of their pedagogical skill. They gained skills that allowed them to further develop their pedagogy after the MS program.
    - Current: "I am comfortable with my ability to handle a college-level chemistry course and to find ways to improve my teaching skills."

<u>Attitudes (A-p and A-c), Knowledge (K-p and K-c), and Skill (S-p and S-c)</u>

The remainder of alumni respondents described themselves using attitudes, knowledge, and skills they possessed as teachers prior to and after participating in the MS program.

- Alum 1 discussed improved PCK in terms of combining chemistry concepts, gaining chemistry content knowledge, and improving their organizational skills.
    - Prior: "Energetic, willing to try new things, didn't always have the greatest depth of knowledge."
    - Current: "Energetic, more focused on organization, able to connect chemical concepts better and in multiple ways."
- Alum 3 shared attitudes they held prior to the MS program and discussed feeling more professionally qualified currently, indicating professional development.

  - Prior: "Proficient and enthusiastic"
  - Current: "Highly qualified. I understand what my worth is and how to navigate the intricacies of school districts."
- Alum 7 expressed their desire for future growth in their chemistry content knowledge but attributed some knowledge gains to the MS program. Improvements to their KoSc indicates improved PCK.
  - Prior: "Ok. Still needing to make sure that my kids are learning what they need."
  - Current: "Feel better. Feel like my knowledge is greater but still needs to [be] better to help students retain mastery."
- Alum 10 gained confidence in their content knowledge through the MS program, which demonstrates improved PCK through improved KoSc.
  - Prior: "Effective."
  - Current: "More confident with content."
- Alum 12 gained confidence in their chemistry content knowledge at multiple educational levels, which indicates improved KoSc and KoCO, thus improving their overall PCK.
  - Prior: "Okay at simple and basic concepts but unsure of higher-level content."
  - Current: "Very confident at high school and college level material."
- Alum 13 discussed improvements to their research skill and content knowledge, which demonstrates improved PCK through improved KoSc.

    - Prior: "Decent and somewhat organized with respectable content knowledge. My rapport with students was always positive if not a bit edgy at times."
    - Current: "My content knowledge and comfort level with constructing research around educational questions have significantly improved."
- Alum 15 gained content knowledge and confidence, as well as improved skill in terms of their laboratory approach, which demonstrates improved PCK through improved KoSc and KoT.
    - Prior: "Lacked depth of knowledge, lacked self confidence in teaching, poor at labs."
    - Current: "Better depth of knowledge, more confident, better and presented and performing labs."
- Alum 16 improved their content understanding through the MS program and gained confidence in their pedagogical skill, which indicates improved PCK through improved KoSc and KoT.
    - Prior: "I think I was pretty good."
    - Current: "I have a much better understanding of a lot of the material and feel much more confident in presenting material."
- Alum 17 stated that the MS program did not help them experience professional development in terms of their classroom teaching, indicating a lack of change in their KoT and KoCO. They did share improved KoSc resulting from the MS program, which positively impacted their PCK.

  - Prior: “Prior to the program, I was a very strong chemistry teacher. I always had different hands on activities and manipulatives for the students, the students were always involved in Hands-On learning from a PBL perspective.”
  - Current: “After the program, I would say that I am still a strong teacher and I still do many of the same activities and labs that I did before. So as classroom professional development I would not say that the program helped me. However, I do now have a deeper understanding of many of the chemistry principles and content at the upper level. Although I have my bachelor’s in chemistry, there's only so much that can be taught at that level. Having a higher level of understanding of specific topics helps me to see and better explain to the students higher level content.”

<u>Background</u>

Some alumni respondents shared details about their background.

- Alum 14 described themselves as a “7-12 Science Teacher” both prior to the MS program and currently.
- Alum 9 described their teaching background prior to their MS program experience.
  - Prior: “I was able to teach college-level labs but not the lecture part of a course.”
- Alum 5 shared their background and discussed their prior skill regarding their laboratory instruction.

    - Prior: "I taught high school chemistry at a private school. I started an AP Chemistry program and wanted a graduate degree to eventually teach for college credit. I was not sure how to conduct inquiry labs and was really just going week by week."
    - Current: "I ended up moving to a 4-year private university. I still 'teach' recitation subsections in General Chemistry."
- Alum 11 shared their prior and current background, while also discussing their prior skill and current confidence levels (A-c).
    - Prior: "Competent, chemistry and physics focused
    - Current: Well, I left education during my time at SDSU and now I run PD for teachers all over the world. So, I'd say I'm pretty confident in my skills.

<u>Summary of Teacher Descriptions</u>

Alumni respondents described how they changed as teachers through the MS program. The main themes for teacher descriptions were:

- Alumni experienced professional development through the MS program by gaining confidence and maturity as teachers.
- Alumni gained chemistry content knowledge, as well as research knowledge, through the MS program and gained confidence in their content understanding. Improved KoSc indicated improved PCK for alumni.
- The MS program equipped alumni with knowledge and experiences that led to improved pedagogical skill (KoT). Some alumni indicated improved KoCO and KoT resulting from the MS program, which indicated improved PCK.

- Alumni shared details of their teaching contexts prior to and after the MS program, with some describing a shift to higher level chemistry courses. This demonstrates alumni's professional development due to the MS program.

Changes Attributed to MS Program

Attitudes (A-c)

Three alumni respondents discussed gaining teaching confidence through the MS program.

- "Because of my experience in the program I am a much more…confident chemistry teacher." – Alum 2
- "I felt more confident teaching atomic theory and electrochemistry." – Alum 5
- "I feel more confident teaching some of the upper material now." – Alum 16

One alumni respondent discussed gaining confidence through obtaining the MS degree.

- "I got more confidence having the backing of the degree." – Alum 11

Another alumni respondent felt accomplished after completing the MS program.

- "Personally, I just feel more accomplished." – Alum 10

Alum 13 discussed a shift in their self-treatment due to the community of other chemistry teachers in the MS program.

- "The program taught me to have some grace with myself when teaching gets tough as these are feelings and realities for many teachers." – Alum 13

Knowledge (K-c)

Three alumni discussed gaining chemistry content knowledge through the MS program. This improvement to their KoSc indicates improved PCK.

- "The course increased the depth of my chemical content knowledge. I feel I have a greater awareness of methods for teaching chemistry." – Alum 1
- "Because of my experience in the program I am a much more knowledgeable… chemistry teacher." – Alum 2
- "Learning the chemistry at a deeper level." – Alum 12

Alum 8 connected their improved content understanding (KoSc) to their pedagogical skill or curriculum organization, which demonstrates improvements to the quality of their PCK resulting from their experience in the MS program.

- "Also, I could go in a lot more depth or do more interesting labs because I understand the information better." – Alum 8

<u>Experience</u>

One alumna discussed their experience as a young female teacher and shared how the MS program allowed them to gain more professional respect.

- "As a young female teacher, most people question my opinions based not on their merit but based on my appearance. Having the masters has squelched a bunch of needless opposition and allowed debates to have academic basis and not 'well, you are still young; you have a lot to learn.'" – Alum 11

<u>Background</u>

Alum 9 discussed how the MS program allowed them to earn the necessary degree to work in academia. They shared positive attitudes (A-c) toward teaching, especially regarding support of student learning.

- "Mine was a unique situation, since I was not a high-school teacher. The program allowed me the credentials to be hired as an adjunct professor. Personally, this change has been a complete joy. I love being in the classroom with students, I love seeing them learning lab skills, I love finding new ways to help them understand the concepts that they haven't yet mastered." – Alum 9

Two additional alumni discussed how the MS degree enabled them to teach dual-credit or college level chemistry courses.

- "Professionally, I am able to teach a dual-credit chemistry class." – Alum 10
- "I now teach college level chemistry CHM 111." – Alum 14

Feedback

One alumni respondent shared a comment coded as "Feedback," which was further analyzed using Codebook 3 and will be discussed in the section below.

Teaching

In terms of teaching, some alumni shared changes to their curricula and pedagogy, which demonstrated improved PCK through improved KoCO and KoT.

- "Greater willingness to stray from traditional teaching and try new things." – Alum 1
- "I am stronger in my curriculum and more willing to tackle more challenging lessons. I am more apt to challenge my students." – Alum 4
- "I was able to create more labs and inquiry-based activities." – Alum 5
- "I changed some of my practices in the regular chemistry class, by shortening up some of the units. I also add some material to my AP class." – Alum 16

Some alumni discussed changes to their overall pedagogical approach, demonstrating improvements to their KoCO and KoT, thus improving their PCK.

- “It validated my pedagogical approaches and helped me bring more data driven inquiry cycles into my own practice.” – Alum 6
- “My pedagogy will now be much more focused on experiential if not at least demonstration based learning in the chemistry classroom.” – Alum 13
- “I also use inquiry and modeling in lessons.” – Alum 14

Alumni also focused on student learning, which combined their KoSt and KoT, thus demonstrating improvements to the quality of their PCK.

- “Teaching more with how the students retain info and learn the information. Making sure students learn the material. Nothing different with anything else. There is a lot more student responsibility.” – Alum 7
- “Thinking through student misconceptions.” – Alum 12

One alumni respondent reflected on sharing their SDSU research experiences with their students (KoSt), connecting to their KoG by making real-world chemistry connections. These comments demonstrate improved quality of Alum 17’s PCK.

- “I have really enjoyed talking to my students about different life research experiments that I have participated in. My students like to hear about the ice lab and how chemistry relates to things beyond the classroom.” – Alum 17

Connecting to interactions that took place in the MS program, Alum 8 discussed the impact of learning from other MS program participants on their teaching practice. These interactions enabled Alum 8 to develop KoT and KoR, thus improving their PCK.

- “Hearing a lot of the ideas from classmates helped me do things differently in my classroom.” – Alum 8

Summary of Teaching

Alumni indicated that the MS program allowed them to improve their teaching practices. The main themes for teaching were:

- After completing the MS program, alumni were more willing to try new teaching strategies, make changes to their curricula, and teach more challenging lessons, thus improving their KoCO and KoT, which improved their overall PCK.
- Alumni also altered their pedagogical approach by implementing more inquiry, modeling, and experiential learning. These changes indicate improved PCK through improved KoCO and KoT.
- Alumni discussed changes relating to their focus on student learning and misconceptions, which demonstrated improved KoSt and KoT, which led to improved quality of their PCK.
- Alumni also indicated improvements to their KoSt, KoG, KoT, and KoR through an increased focus on real-world chemistry connections and gaining new teaching ideas from other MS program participants.

Interaction

Alum 5 discussed continued collaboration with the community that was formed during the MS program.

- "I built a community that I enjoyed collaborating with even from afar." – Alum 5

Reflection

Alumni also shared reflective comments regarding MS program outcomes. Alum 3 reflected on how interactions during the MS program impacted their professional sense of self-worth.

- "Through conversations in South Dakota I realized how underappreciated I was as an educator. Now I value my time much more than before. I also understand the logic and processes in school districts and what to believe or not, based on my district's reaction to me getting a Master's. I also understand what it takes to teach a high-quality chemistry class in an advanced level." – Alum 3

Alum 11 expressed enjoyment regarding the reflection that took place through the MS program's requirements.

- "I enjoyed the introspection on the activities and projects." – Alum 11

Alum 17 indicated improvements to their KoG as a component of their PCK, which was impacted by the MS program's research experiences.

- "I think the most important part of the program is understanding and finding ways to convey to the students that chemistry is just more than balancing equations, stoichiometry and gas laws and the research portion helped to provide insight into different content realms." – Alum 17

<u>Summary of Changes Attributed to MS Program</u>

All alumni respondents identified changes to their teaching confidence, pedagogical approach, and chemistry content understanding that could be attributed to their experiences in the MS program. The main themes were:

- Alumni gained chemistry teaching confidence through the MS program, with some respondents also describing shifts in their self-treatment based on learning about other teachers' experiences in the MS program. These attitudes included having more grace with themselves during teaching challenges, garnering more professional respect, and recognizing their value as educators.

- The MS program helped teachers develop or deepen their KoSc, which demonstrated improved PCK.
- Some alumni discussed shifts in their teaching contexts, including gaining credentials through the MS program necessary for teaching college-level or dual-credit chemistry courses. This demonstrates the MS program's impact on alumni's professional development.
- Alumni indicated changes to their teaching practices, including the implementation of new teaching strategies, curricula, and pedagogical approaches, as well as an increased focus on student learning, misconceptions, and real-world connections. These changes indicated improvements to alumni's KoCO, KoT, KoSt, KoG, and KoR, which indicated improvements to their overall PCK. Some alumni combined these knowledge bases, which demonstrates improvement to the quality of their overall PCK.
- One alumni respondent indicated that collaboration with other MS program graduates existed past the MS program experience. This demonstrates the continued impact of the MS program on its participants.

MS Program Reflection

Attitudes (A-c)

Alum 9 indicated improvements to their teaching confidence due to the MS program.

- "I feel confident in my ability to teach at a college level and provide a challenging, worthwhile course to the students." – Alum 9

Knowledge (K-c)

Alumni indicated improvements to their chemistry content knowledge resulting from their participation in MS program courses. Improvements to their KoSc improved their overall PCK.

- "The content-based courses challenged me, and I have a deeper and broader understanding of chemistry and connections to other areas of science." – Alum 1
- "I liked being challenged and learning more about chemistry." – Alum 2
- "Great! Learned a lot and increased my knowledge." – Alum 7
- "I learned a lot in all of my classes." – Alum 11
- "The chemistry content courses provided refresher material that improved your general chemistry knowledge." – Alum 14
- "I think [the MS program] was challenging in a good way that forced me to learn, higher level material." – Alum 16
- "I learned a lot of content." – Alum 17

Alum 12 described how the program improved their overall teaching effectiveness through the development of a stronger content understanding (KoSc), which improved their overall PCK.

- "It was great. I feel like I came out a better teacher with a better understanding of chemistry." – Alum 12

Feedback

Three alumni respondents shared statements coded as "Feedback," which were further analyzed using Codebook 3 and will be discussed in the section below.

Interaction

Two alumni discussed the value of interacting with other MS program participants. Alum 2 appreciated interactions with MS program participants and instructors during their MS program experience.

- "I liked meeting and collaborating with other chemistry teachers from around the country. I enjoyed interacting with the professors." – Alum 2

Alum 9 discussed continuing to collaborate and interact with MS program participants past graduation, which has helped them continue their professional development.

- "I have maintained friendships with people in the cohort. I have asked for and received help and offered help in teaching and lab questions." – Alum 9

Reflection

Many alumni ($N = 13$) reflected that they had a positive, enjoyable experience in the MS program.

- "I thoroughly enjoyed my experience in the program." – Alum 2

Several alumni ($N = 8$) reflected specifically on the contribution of the summer research component of the MS program to their overall enjoyment. Some of these eight respondents discussed the impact of the summer laboratory experiences on their teaching, indicating improvements to knowledge and skills (KoSc) that improved their overall PCK. Alumni also reflected that the courses were challenging, yet manageable.

- "I enjoyed the lab experiences and my research project." – Alum 1
- "I enjoyed it. I enjoy the flexibility of online classes throughout the school year and the hands-on classes during the summer." – Alum 10

- “I enjoyed the program. The summer sessions provided lab experience that was very beneficial.” – Alum 14
- “I thoroughly enjoyed the program. I really enjoyed the summer experience on campus.” – Alum 15
- “Very positive and though I do not miss the stress of weekends I do miss the learning and time with peers. The summers will be particularly missed.” – Alum 13
- “I enjoyed the program a lot. I liked working in the labs over the summer and felt the courses were the right level of difficulty.” – Alum 5
- “I'm very happy with my experience in the program…I enjoyed my summer experience of working in the lab and living in the dorms. The content was challenging but doable while working at full-time teaching job.” – Alum 17
- “This program was nothing but amazing. The collaborative experiences and the time in research labs was [sic] extremely impactful on my teaching.” – Alum 3

Three alumni expressed their desire to do the MS program again, demonstrating its high impact.

- “I loved it this program. I would love to do it again.” – Alum 8
- “I absolutely loved my experience in the program…I would absolutely do it again if given the chance at a higher level.” – Alum 16
- “I loved my experience at SDSU. The professors were helpful. I would definitely have done the program again.” – Alum 4

Alum 9 indicated that the impact of the MS program extends “long after” the experience itself.

- "I found the program to be extremely useful long after the two years were over." – Alum 9

Summary of Reflection

Some respondents discussed the value of the summer component of the MS program combined with its virtual coursework, as well as the value of the action research project. The main themes for reflection were:

- All alumni that provided reflected comments expressed positive feedback about the MS program, stating that they enjoyed the on-campus summer research experiences, learning in community with other science teachers, and being exposed to challenging chemistry content.
- Alumni expressed their desire to repeat the MS program, demonstrating its high impact on its participants.

Summary of MS Program Reflection

Alumni reflected on their overall MS program experiences. The main themes were:

- The MS program content courses challenged participants and enabled them to develop deeper chemistry content knowledge (KoSc), which improved their overall PCK, teaching confidence, and teaching effectiveness.
- Interacting with other MS program participants and instructors helped alumni develop knowledge and skills to bring back to their classrooms. One alumni respondent discussed continuing to collaborate with MS program participants past their time in the MS program, demonstrating its continued impact on teachers.

- Alumni reflected that they enjoyed the MS program, especially the summer laboratory research experiences. Some alumni expressed their desire to repeat the MS program, demonstrating its impact on participants.

Suggested Changes

All alumni respondents but one shared feedback regarding changes they would make to improve the MS program, which will be discussed using Codebook 3 below. The remaining participant was not able to come to SDSU for the summer experience in Summer 2020 due to the COVID-19 pandemic and they reflected on their desire to come to SDSU both summers.

- "I wish my second summer I had been able to go up there for the lab part." – Alum 16

Additional Feedback

Several alumni respondents ($N = 13$) shared additional feedback regarding positive or negative aspects of their experiences in the MS program. These statements were further analyzed using Codebook 3 below.

Codebook 3

All alumni respondents ($N = 17$) shared statements coded as "Feedback," which were further analyzed using Codebook 3. These coding frequencies are shown in Table 222 below.

Table 222. Alumni Survey Coding Frequencies – CB3

Code	**Abbreviation**	**Total Number of Teachers Represented (*N* = 17)**	**Percentage of Total Responses (%)**
Course Feedback	CF	3	17.6
Program Feedback	PF	17	100
Course Delivery Feedback	CDF	2	11.8
Logistical Feedback	LF	2	11.8

<u>Course Feedback</u>

Alum 2, who participated in the MS program from Fall 2017 to Summer 2019, provided feedback on CHEM 775.

- "The only class I felt could be improved was the organic chemistry class. It was a bit chaotic in its organization." – Alum 2

Alum 2 also shared positive feedback about the lab safety course.

- "I also feel that the Lab Safety course was extremely valuable. I'm very grateful I took it and I felt it was valuable enough to make a required summer course." – Alum 2

Alum 17, who participated in the MS program from Fall 2019 to Summer 2021, also provided constructive criticism about the biochemistry component of CHEM 775.

- "I very much disliked the biochemistry course and the curriculum. The class reminded me as to why I did not go into biochemistry initially, which is because it was pure memorization without any relevance taught in the class." – Alum 17

Alum 9, who did not indicate the dates of their participation in the MS program, hoped for more challenging topics in the CHEM 775 and CHEM 772 courses.

- "I don't know if this applies to a lot of people in the program, but some of the chemistry courses could have been a little more difficult. I would have liked some more in-depth organic, biochem, and physical chemistry (thermo) units." – Alum 9

Program Feedback

Four alumni stated that they would not change anything about the MS program. Four additional alumni shared positive feedback about the MS program.

- "I thought the program was good overall." – Alum 15
- "I wouldn't change anything it was very well done!" – Alum 16
- "Overall I had a very positive experience in this program." – Alum 12
- "I'm not sure if I could think of any changes. Running that whole program is a large undertaking…I was happy with my experience. I felt like I was learning with friends. It was a very positive and personal experience." – Alum 1

Alum 6 shared positive and negative components of the MS program.

- "Parts were really great (the summer sessions, research, and Instructor A's classes) and parts were not as great ([former instructor's] class)." – Alum 6

Some alumni expressed interest in participating in an extension of the MS program; for example, if the department were to offer a doctoral option.

- “I would also like the option for a traditional thesis degree or a continued PhD/EdD.” – Alum 11
- “If there was a doctorate program, then I would take it in a heartbeat.” – Alum 3

Several alumni shared feedback regarding instruction and interactions with SDSU MS program faculty. Most of these responses were positive.

- “All of the staff involved gave me all the attention I needed and really cared about all of us.” – Alum 1
- “I loved my experience in the program. Instructor A, Instructor B, and the other professors involved were fantastic!” – Alum 2
- “Instructor B and Instructor A made the program what it is. Through thoughtful questions, they would help us think through the material and how to teach it.” – Alum 8
- “Loved the program. Instructor A is the best!” – Alum 10
- “Instructor A will be tough to replace when they retire...” – Alum 13
- “I think SDSU professors do a good job of taking where you are at and pushing you further.” – Alum 15

A few alumni shared negative feedback about MS program instructors, most of which related to communication.

- “Sadly, there was a professor who was unorganized and wouldn't communicated deadlines appropriately, so it really put a damper on that semester because of all the frustration.” – Alum 8

- “I didn’t get as much out of that process because I didn’t really communicate with my advisor. The instructor also just left unannounced in the Summer, so I’m not sure that was anyone’s fault in the program.” – Alum 5
- “I enjoyed my time in my program, with the exception of a few professors. I feel that most of the courses set out to improve our teaching abilities.” – Alum 11

In terms of MS program content, two alumni expressed interest in having courses focused on data analysis. Alum 5 hoped to have more statistics preparation related to educational research, while Alum 12 wanted more support related to data analysis in the classroom.

- “Add a bit more background in educational research and statistics. I was hoping for more of an in-depth course on research and statistics to be accompanied with the Action Research course.” – Alum 5
- “I would like to see a better use of how to use data analysis in a classroom. Students are required to read and analyze data and building labs for that is difficult.” – Alum 12

Alum 5, who participated in the MS program from Fall 2016 to December 2018, also shared their interest in courses that now exist for the MS program.

- “A lab safety or waste disposal short course would also be nice.” – Alum 5

Alum 8 provided suggestions regarding the MS program curriculum, which they proposed could focus more on AP Chemistry content.[2]

- “I think all aspects of the program served a purpose - I wouldn't change much. I would revamp the curriculum to focus a little more on AP material. For instance, little less on the math in nuclear, but keep the overall unit because it's so interesting. That would free up some time for some more thermodynamics. I would also do the higher-level questions like there are, but also make us either do or make some AP level questions. That way, we can see the types of questions our students will have AND have some answer keys done to the work, already." – Alum 8

Two alumni provided positive feedback about the MS program format, highlighting one of its purposes to allow for teachers to complete the degree while remaining in the classroom.

- "I felt the program was a great opportunity for teachers to earn a science degree without having to take a leave of absence." – Alum 4
- "I liked the flexibility of the program and how it was specifically tailored for chemistry teachers." – Alum 17

Alum 13 emphasized the value of the in-person summer component of the MS program, stating that it should remain a requirement.

- "Do not change the in-person component...I know that some people were seeking other avenues for filling out their credits and I fear the summer component could become watered down if too many folks opt for more online classes instead." – Alum 13

Alumni also mentioned that they would (and do) recommend the MS program to other science educators due to their own positive experiences.

- "I have recommended this program to high school chemistry teachers that I know. I believe it is a unique program that can be handled along with regular life and that it prepared me very well for the chemistry teaching that I now do and love. It was a fantastic experience for me, I really enjoyed the summer sessions in

Brookings, and I hope that many others are able to benefit from the program." – Alum 9

- "I highly recommend the program to other professionals constantly." – Alum 15
- "I absolutely loved the program, I would highly recommend it to everyone (and do) I think it really did make me a better teacher, and a better chemist." – Alum 16

Summary of Program Feedback

All participants shared program feedback. The main themes were:

- The majority of respondents shared positive feedback about the MS program or expressed that they would not make any changes.
- Alumni expressed that they would (and do) recommend the MS program to other science teachers. They also expressed interest in continuing their MS program experience if a doctoral program were offered at SDSU.
- Alumni shared suggestions for adding statistics or data analysis courses or adapting the MS program curriculum to align with AP Chemistry content.[2]
- Alumni appreciated that the MS program was tailored to teachers currently in the classroom and enjoyed the in-person summer experience.
- Most alumni shared positive feedback regarding instruction and interactions with MS program instructors; however, a few alumni shared negative feedback about instructor communication and instruction.

Course Delivery Feedback

Two alumni provided feedback regarding course delivery. Alum 3, who did not indicate the dates of their participation in the MS program, desired more face-to-face interaction during video help sessions. Since the COVID-19 pandemic, there has been more face-to-face interaction during Zoom sessions.

- "I would increase the face to face time between students. During the help sessions Instructor A would be the only person with a camera on. It would be nice to have time where students could interact face to face." – Alum 3

Alum 6 desired for more synchronous work through the MS program.

- "Asynchronous learning was really helpful in the flexibility of being able to attend to our full-time job when and how we needed to, but some synchronous work would have deepened the learning as well as established a better network." – Alum 6

Logistical Feedback

Alum 10, who participated in the MS program from Fall 2016 to Fall 2018, hoped for a change in the MS program's length.

- "Have it end in 2 years, not 2 1/2 years." – Alum 10

Alum 17, who participated in the MS program from Fall 2019 to Summer 2021, expressed their appreciation for the MS program's hybrid format.

- "This was one of the only programs that was an online master's chemistry program but compensated by the online portion with the summer sessions, which I thought was awesome, even though I was only able to do one in person due to COVID." – Alum 17

Summary of Alumni Survey

In the alumni survey, teachers discussed how they have changed as teachers due to the MS program, reflected on their MS program experience, and shared feedback on the MS program, including its courses, instructors, course delivery, and logistics. The main themes for the Alumni Survey were:

- The MS program enabled alumni to develop teaching confidence through strengthening their chemistry content knowledge. Developing KoSc improved their teaching effectiveness and overall PCK.
- The MS program allowed alumni to gain knowledge and experiences that led to improved pedagogical skill. Improvements to their KoCO, KoT, KoSt, KoG, and KoR indicated improvements to their PCK. Some teachers combined these knowledge bases, which indicated improved PCK quality due to the MS program.
- Some alumni were able to teach higher level courses, including dual-credit or college courses, after obtaining their MS degrees. This demonstrates the MS program's impact on its participants' professional development.
- Alumni expressed their desire to repeat the MS program or participate in a doctoral program at SDSU if offered.
- Alumni stated that they would (and do) recommend the MS program to colleagues in science education.
- Interacting with other teachers in the MS program allowed alumni to further develop knowledge and skills. These interactions supported participants' PCK and professional development.
- Alumni provided feedback on how certain MS program courses could be improved in the future, including changes to communication, the depth of content, and relevance of content.

- Alumni appreciated the primarily virtual format of the MS program, which allowed them to remain in the classroom, and also valued the opportunity to be on campus for the summer sessions. Alumni especially enjoyed the summer laboratory research experiences, which some felt strongly should remain a requirement. They also hoped for a higher focus on synchronous meetings in virtual courses.
- Alumni suggested changes for the MS program, including the addition of statistics or data analysis courses and a greater focus on the AP Chemistry curriculum.[2]
- Most alumni enjoyed the MS program and its instructors overall and did not express their desire to make any changes. However, a few alumni shared negative feedback about some instructor communication and instruction.

CHAPTER 6: COURSE FEEDBACK

Purpose of This Chapter

Upon evaluating this MS program, it was essential to gather feedback from past and current program participants about all aspects of the MS program. Feedback from the narrative participant was included in the Chapter 4. Feedback from the alumni was included in Chapter 5. All feedback from MS program participants from Fall 2021 to Summer 2023 was sent directly to instructors for the MS program and will not be included in this dissertation.

Course Benefit and Value for Money Feedback

The only feedback that will be presented from the MS program participants relates to Likert scale responses concerning the course benefit and value for money from the end-of-semester surveys. After finding the average scores for these two Likert scale questions, I sent compiled data to MS program participants from Fall 2021 to Spring 2023 for member checking. Their anonymous responses were coded using Codebook 3. Coding frequencies can be found in Table 223.

Table 223. Course Benefit/Value for Money Coding Frequencies – CB3

Code	**Abbreviation**	**Frequency of Responses (*N* = 43)**	**Percentage of Total Responses (%)**
Assignment Feedback	AF	3	7.0
Course Feedback	CF	22	51.2
Program Feedback	PF	13	30.2

Course Delivery Feedback	CDF	4	9.3
Logistical Feedback	LF	1	2.3

Course Benefit

In the end-of-semester surveys, participants were asked to respond to the following question regarding course benefit: “How would you rate the overall benefit of the course you took this semester? (Was taking the course beneficial?) [Likert Scale from 1 (not at all beneficial) to 6 (very beneficial)].” Respondents to the member checking survey were then asked to respond to the following data for average course benefit. The average Likert scale scores for course benefit can be found in Figure 2. This chart was embedded in the member checking survey.

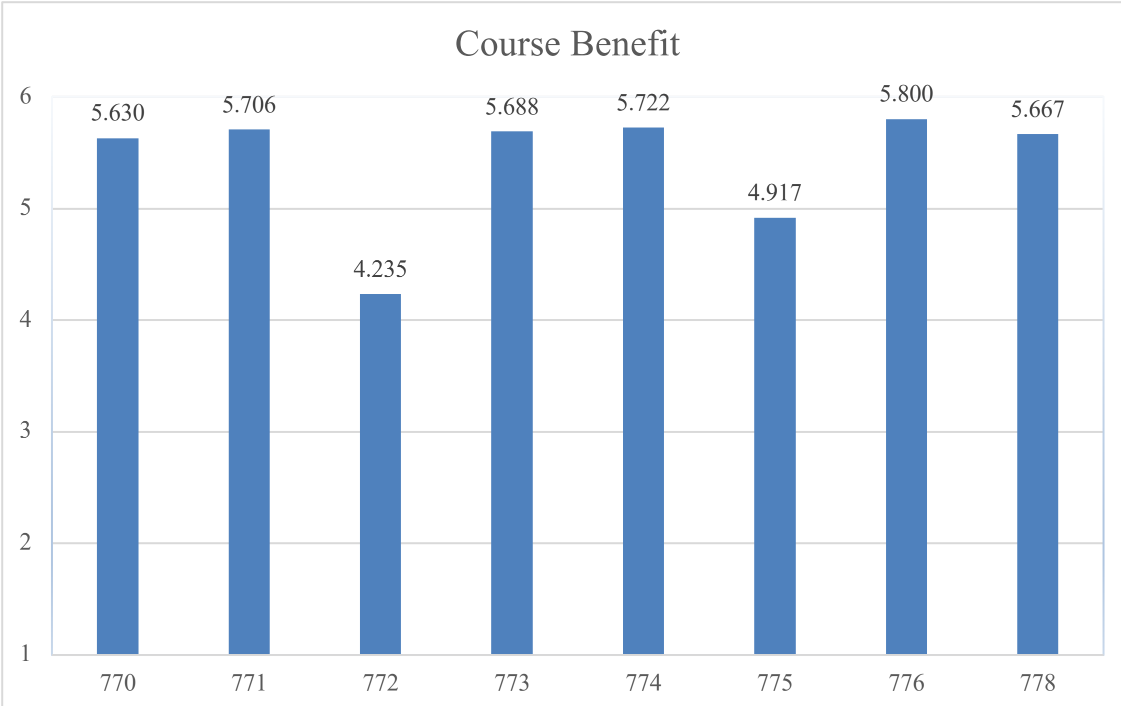


Figure 2. Ratings for course benefit from the end-of-semester surveys from Fall 2021 to Spring 2023.

Seven respondents explicitly stated that they agree with the average ratings for course benefit. Ten of the thirteen respondents provided personal opinions on the ratings, which further validated this dataset.

Assignment Feedback

One teacher remarked on the value of the module assignments in terms of bringing new content into their instruction.

- "The CoRe and Teaching Script assignments were a huge part in incorporating these new topics into my teaching."

Another participant detailed how they gained knowledge through interactions with other MS program participants in course discussion forums.

- “I learned a lot from what the other teachers had to say in the discussion forums.”

Course Feedback

One teacher discussed that the MS program courses were beneficial in terms of chemistry content and interactions that took place through discussion forums.

- “I know for me personally that all of the courses offered good to great value in terms of the content that was covered and the depth to which conversations went on discussion boards, etc.”

Three teachers shared that the courses that benefitted them the most were applicable to their teaching. The first respondent stated that the courses improved their KoSc, which demonstrates improvements to their PCK.

- “Most of the course was directly applicable to what I teach. Some of the content went beyond the scope of high school chemistry, even for AP. However, I solidified my content knowledge.”
- “I think the information covered and the discussions were applicable to my teaching.”
- “The courses contained in-depth information that is going to aid me in teaching my future classes. I have already thought about different topics I will be able to incorporate.”

Another teacher reflected that variation in the ratings could be due to personal preference for content knowledge they hoped to gain or strengthen through the MS program.

- “There doesn't appear to be all that much variation between CHEM 770, 771, 773, 774, 776, 778. Any variation in the benefit teachers perceive from these courses is likely due to subtle differences in prior experiences with the content from teacher to teacher. For example, I found CHEM 770 to be extremely beneficial because I felt it helped me close numerous gaps in my own understanding of quantum theory. I also had an intense desire for such gaps to be resolved not only to benefit my teaching but to satisfy my own understanding. However, I can imagine others not being as attracted to or comfortable with quantum theory and its role in their own teaching. Therefore, it seems reasonable why a course like CHEM 770 would score a bit lower than the courses previously mentioned above."

Five teachers discussed the ratings for course benefit for CHEM 772 and/or CHEM 775. They reiterated that the reasoning behind these ratings may not be due to the challenging nature of the chemistry content itself. Some teachers provided constructive feedback for how the organization and content of the courses could be improved in the future.

- "It's hard not to see the noticeable dip in average rating when looking at CHEM 772 and 775. At face value, the content studied within these respective courses could be described as being a bit more advanced and less likely for high school teachers, including myself, to notice immediate connections to how these courses would directly impact high school chemistry curriculum. I interpret these lower average course ratings to be more a reflection teachers' feelings about the instructor of each course rather than about the content of the courses itself."
- "However, there is no denying that there was a difference in the 772 and 775 classes with regard to the style of delivery, the assignments that were required, the online platform(s) used for content delivery and practice, etc. The offering of content in those courses was often less organized and felt more scattered or hard to find, which meant that many of us ended up seeking out other sources for the

background information from which it sometimes felt like we were teaching ourselves to some extent. It felt less polished and rather less streamlined."

- "I agree that the two courses that benefited me the least were CHM 772 and 775. I find this unfortunate because I was more interested in these topics than some of the other courses. The way that the class was structured did not help me learn the material."
- "All courses were beneficial, with two courses in particular of less value. I agree that 772 was less rigorous (I would have liked more problems to solve and less projects)."
- "I would put [CHEM 775] below [CHEM 772]."

Two teachers discussed course benefit in terms of the instructor's approach.

- "I think that it's hard to say whether it's beneficial without clarifying the benefit. I don't necessarily know what I'll be doing moving forward with this degree, so different courses might end up being more or less beneficial. I will say that I felt [CHEM 770, CHEM 771, CHEM 773, and CHEM 774] were much better organized and I learned the most in those courses."
- "I am happy for Instructor B's ratings as I think some folks were critical of their approach though I enjoyed it and found it very beneficial."

Two teachers remarked on the benefit of the summer campus experience. Both teachers referenced conversations they have had with peers regarding the benefit of MS program courses. The second teacher also discussed the value of the pedagogical course (CHEM 778).

- "CHEM 776 having the highest average rating doesn't really surprise me considering the type of conversations I've had with others throughout our experience last summer. Crunching so much into a 2-week span while still attaining the highest average rating says a lot about the value the course provides teachers with."
- "The 776 and 778 courses are amazing aspects to this program in addition to the core content coursework. There is no wonder that it is easy to speak passionately to colleagues and others about the overall benefit of being part of these classes."

Program Feedback

One teacher discussed the value of interacting with SDSU professors and MS program participants to improve their teaching effectiveness. These interactions allowed them to gain knowledge that they could apply to their instruction, which demonstrates improvement to their overall PCK.

- "In addition to the assignments, the professors and classmates in these courses were a vital component to becoming a better more effective teacher. They shared their knowledge and experience with me, which now I will be able to utilize within my classroom and for my students."

Course Delivery Feedback

One teacher confirmed the trend for average ratings for course benefit by discussing the inherent benefit in MS instructor's course delivery.

- "I am not surprised by these ratings based on conversations had with colleagues about who we thought presented material in the best way with the most benefit."

Course Value for Money

In the end-of-semester surveys, participants were asked to respond to the following question regarding course value for money: “How would you rate the value for money of the course you took this semester? (Was taking the course "worth it"?) [Likert Scale from 1 (not at all worth the money) to 6 (very much worth the money)].” Respondents to the member checking survey were then asked to respond to the following data for average course value for money. The average Likert scale scores for value for money can be found in Figure 3. This chart was embedded in the member checking survey.

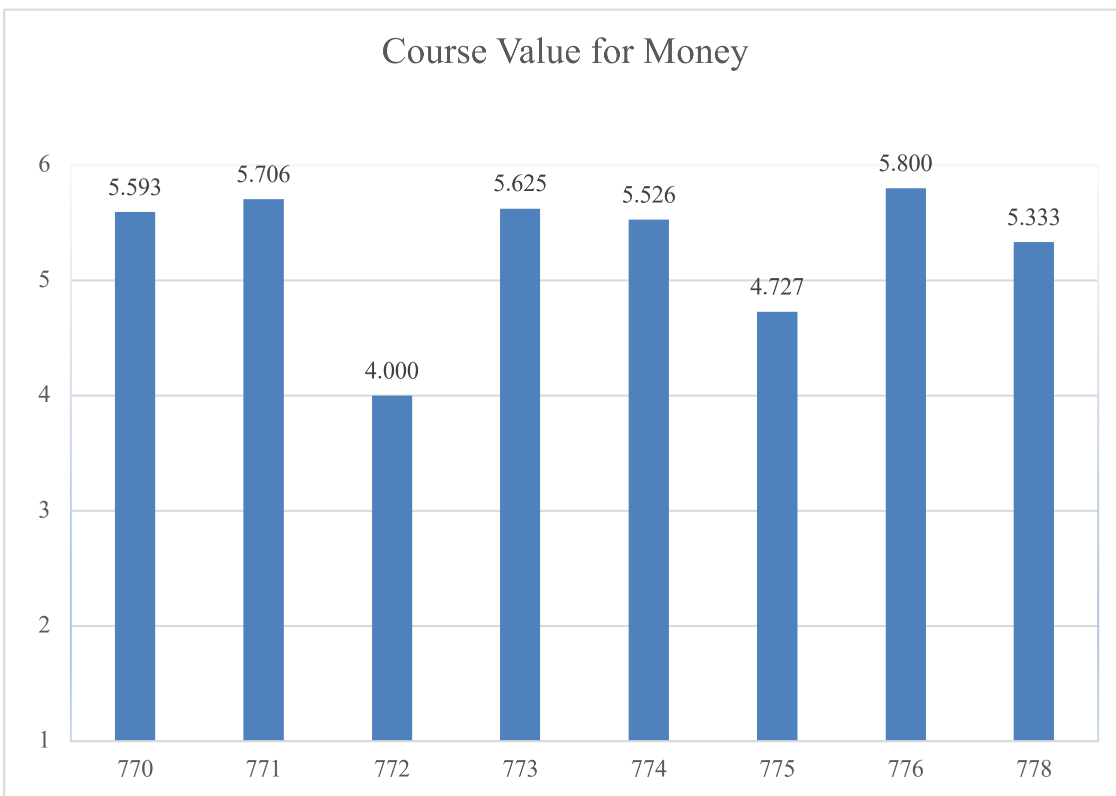


Figure 3. Ratings for course value for money from the end-of-semester surveys from Fall 2021 to Spring 2023.

Ten respondents explicitly stated that they agree with the average ratings for course benefit. Nine of the thirteen respondents provided personal opinions on the ratings, which further validated this dataset.

Assignment Feedback

One participant shared the value of different assignments in the CHEM 773 course.

- “The [CHEM 773] discussion forums were valuable and so were the problem sets.”

Course Feedback

One teacher confirmed the trend for the value for money ratings, but remarked their surprise that CHEM 778 scored lower than most of the chemistry content courses.

- “There seems to be a similar trend to the one about overall benefit. This isn't too surprising considering people are likely to assign greater value to something they feel is beneficial to their teaching as well. I do find it interesting that the one course centered around pedagogy (CHEM 778) scored lower than the content-dominated courses, excluding CHEM 772 and 775.”

Along with the previous comment, four additional teachers remarked on the ratings for CHEM 772 and/or CHEM 775.

- “With respect to CHEM 772 and 775, the drop in average ratings can easily be explained by teachers' perceptions of the instructor. Those two courses felt far less personal than the others largely due to how it was structured.”

- "The 775 course compared to the other 3 courses was somewhat less engaging and while it did cover the content, it seemed to be somewhat less geared towards teaching the topics or covering related or common content in a high school classroom."
- CHEM 772 and CHEM 775 "were not as valuable/beneficial as [CHEM 770, CHEM 773, and CHEM 774]. I expected more problems to solve to dig deeper into the concepts found in thermochemistry as opposed to what we actually did in the course."
- "I agree that CHM 772 and 775 were designed in a way that I did not feel like I was getting my money's worth."

One teacher stated that "the courses where [they] learned the most were probably" CHEM 770, CHEM 771, CHEM 773, and CHEM 774.

Another teacher remarked that the courses they have taken through the MS program have allowed them to increase their KoSc and improve their teaching effectiveness, which indicated improved PCK.

- "CHEM 770, 771, 773, 774, and 775 allowed me to increase my knowledge of chemistry and helped me to become a better teacher. For me, this was worth the money because I don't think I would have had the discipline to learn all of this on my own."

Program Feedback

One teacher shared positive feedback regarding assistance they received from instructors for the MS program.

- “In addition, I couldn't have comprehended the information without the help of the professors. The professors were an invaluable resource for my questions to be answered.”

They also appreciated the value of learning from other MS program participants, which demonstrates the impact of interactions on teachers’ learning and teaching. These connections allowed this participant to develop stronger PCK.

- “On top of the professors, my classmates contained a wealth of knowledge and experience that I was able to take back to my classroom as well. It would've taken me years to develop the connections I have gained throughout these courses and my time in the program.”

One participant provided feedback on the MS program by expressing the relevance of its content to their own teaching. They shared an example by offering course feedback.

- “Most master’s programs are not geared towards high school chemistry. My first master's was a complete waste of money in terms of what I could take back and apply to my classes. Chem 773 was directly related to what I teach.”

One teacher shared that they actively recommend the MS program.

- “In general, this program is affordable and valuable, and I continue to recommend it to my peers or anyone who will listen.”

Course Delivery Feedback

Teachers provided feedback for course delivery. One participant hypothesized that the CHEM 778 course would be ranked higher if it took place in person, stating that pedagogical skill can be better developed through the active implementation of teaching strategies.

- “I see this subtle dip in rating for CHEM 778 as more of a function of the fact this the program is predominantly online. Gaining value from something that focuses on pedagogy tends to most likely occur when people have the opportunities to physically interact and implement the pedagogical ideas being learned.”

Another participant shared feedback on the course delivery of CHEM 772 and CHEM 775.

- “Additionally, I know several people who didn't feel like [CHEM 772 and CHEM 775] were so much ‘taught’ but instead ‘consumed.’”

Logistical Feedback

One participant shared logistical feedback regarding the CHEM 772 and CHEM 775 courses.

- “Lastly, there was a noticeable lack of organization and clarity within [CHEM 772 and CHEM 775] that led to confusion at various points.”

Summary of Course Benefit/Value for Money Data

Figure 4 displays the matrix of average ratings for course value for money versus course benefit for MS program courses.

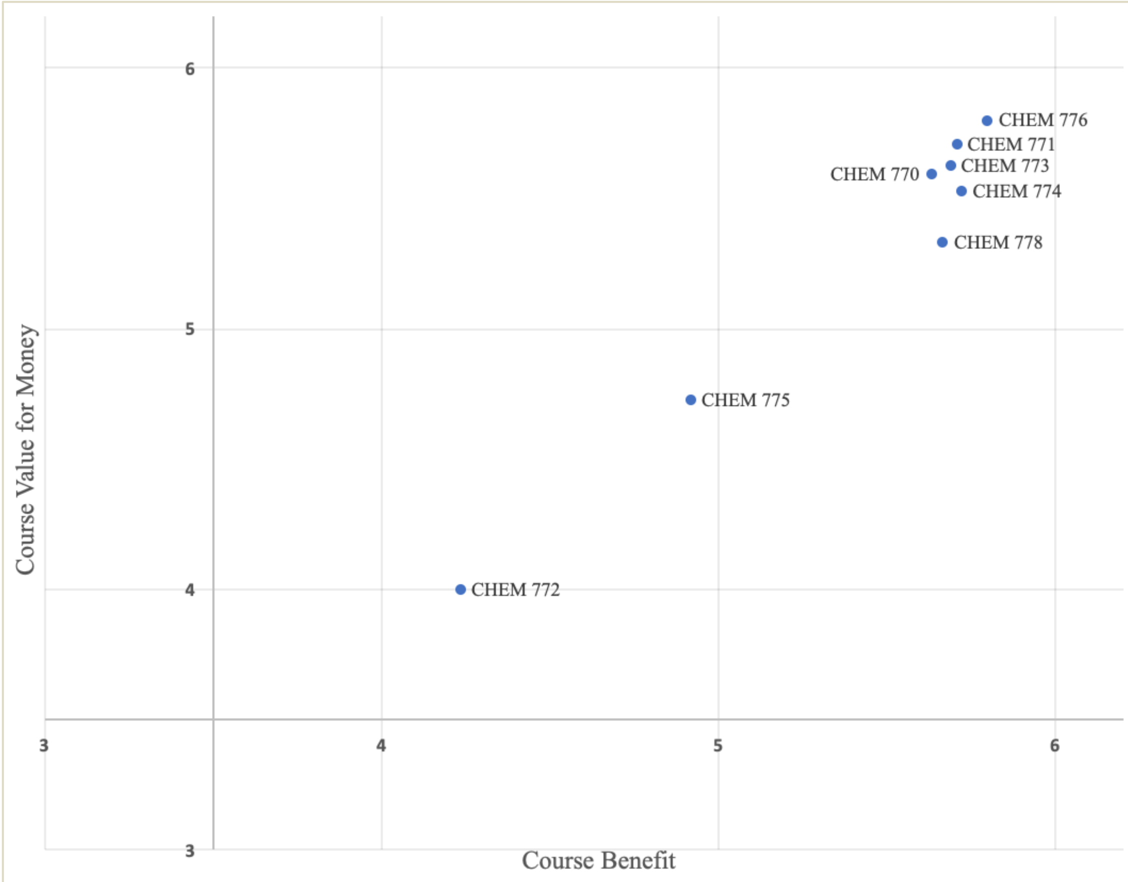


Figure 4. Matrix displaying course value for money versus course benefit for MS program courses.

These results indicate that courses with high benefit also had high value for money. Teachers felt that the courses that most benefitted them – by enabling them to develop knowledge or skills they could apply to their teaching – were more financially "worth it."

Additional Feedback on MS Program Courses

To conclude the member checking survey, participants were asked to share any additional thoughts about their experience in MS program courses. Eight respondents shared additional feedback, which were all coded as "Program Feedback."

Program Feedback

All eight respondents shared positive feedback about the MS program. Half of these teachers (*N* = 4) discussed content knowledge and resources they have gained through the MS program, which demonstrates improved PCK through their development of KoSc and KoR. Teachers also discussed gaining teaching confidence due to improved content understanding.

- "I learned so much more about chemistry that has really helped me to be a better chemistry and AP chemistry teacher. I actually understand the chemistry now and can help students really dig into the content to deepen/broaden their understanding."
- "I love the emphasis on improving content understanding for teachers. The content knowledge I have gained from all of these courses have made me a more well-rounded chemistry teacher and have given me an overall greater sense of confidence in my discipline."
- "I will be utilizing the knowledge and resources gained for years to come."
- "So far I have learned a lot and found that the courses have benefited and will benefit my teaching practices moving forward."

Teachers shared positive attitudes toward the MS program courses and the MS program as a whole. One participant stated that the MS program courses supported their professional development as a teacher.

- "I loved my time in the program at SDSU! I hope they are able to continue to offer this program and that Instructor A keeps their enthusiasm for the program forever."

- “It's a fantastic program. I'm so impressed with the courses they design and the care that they put into their advising for each and every student.”
- “I have had a great experience in this program and all of its courses.”
- “I have only taken 1 course so far and it was awesome. I only wish I had discovered this program sooner!”
- “I am really loving the courses. They are interesting and helping me become a better teacher.”
- “The MS program as a whole is fabulous. and I see myself taking more of the 600 level classes in the future to add those tools to my portfolio as well, if that is possible.”
- “I look forward to the future courses I have yet to take over the next 3 semesters.”

One teacher provided additional feedback for the MS program including the value of their action research project, the campus research experience, and their interactions with other MS program participants.

- “My research was invaluable as well as the time I spent on campus in a research lab. I loved being around people who are so passionate about chemistry (and science) and having that opportunity to collaborate with people who are intelligent and well spoken.”

Another teacher shared constructive criticism regarding the courses that were rated the lowest, but still shared positive feedback about these courses and the MS program overall.

- “I recognize that not all of the courses can be taught by one or two faculty members, but there is perhaps some worth in exploring other options in the courses where ratings come in lowest. In the meantime, I still gained fundamental value in my content 'toolbox' from both 772 and 775 even if the structure didn't correspond to how I judge I learn new content best."

Two additional participants shared that they actively recommend the MS program to other science teachers.

- "I have been and will continue to be a loud advocate for people looking for a program like this."
- "I recommend this program to anyone who will listen."

Summary of Course Feedback

MS program participants found all core courses to be beneficial and financially worth the cost. All courses had ratings greater than or equal to 4 on a Likert scale from 1 to 6, with 6 indicating high benefit or value for money. Many respondents felt that the core course content was applicable to their teaching and supported improvements to their KoSc and KoR, which led to improvements to their overall PCK. Respondents valued CHEM 776 and the summer campus experience overall, particularly in terms of the opportunity to engage with other MS program participants. The summer component of the MS program enabled teachers to further develop PCK in community with one another. Additionally, MS program participants and the MS program instructors supported participants' PCK and professional development. While much of the feedback was positive, there were some negative issues that respondents expressed. One specific issue surrounded the need for improvements to the CHEM 772 and CHEM 775 courses in terms of course organization and delivery. Respondents also stated that they actively recommend the MS program to other science teachers. This member checking provided support for the value of the MS program courses, as well as the MS program overall.

CHAPTER 7: CONCLUSIONS

Overview of Conclusions

The two-year narrative study of the MS Chemistry – Chemical Education Specialization program identified learning outcomes for MS program participants, including PCK change and professional development. This conclusions chapter will: detail the overall themes from analysis; respond to the study's research questions; discuss trends in PCK development; describe participants' focus on their own learning and teaching, as well as their students' learning; outline limitations for the study; and provide suggestions for the MS program moving forward.

Overall Themes from Analysis

Several themes emerged from the individual and program narrative data. These themes were present in both datasets, showing that the overall MS program population agrees with data collected from Taylor, the narrative participant.

- Professional reinvigoration

Through their experience in the MS program, teachers are re-inspired and have increased motivation for applying new content and strategies to their teaching. By developing connections with other MS program participants, teachers were exposed to new teaching ideas. This improvement to their KoR not only increased their overall PCK but inspired teachers to make changes to their instruction.

- Community and collaboration

The MS program allowed for the creation of a network of teachers, especially for those who are the only chemistry teacher at their school. Apart from MS program requirements, participants exchanged teacher-initiated resources, including Zoom study groups, group chats, and shared online folders for resources. The summer campus experience is an essential part of the program, in part because it gave teachers the opportunity to interact, share experiences, and learn from each other. Through this process, they established a support network.

- "My biggest takeaway is that I am not in this alone. I have a lot of support, and I feel better knowing that there are common problems most science/chemistry teachers face." – Teacher 47, Su23, SJ#3

Teachers also discussed collaborating with each other in the future past their completion of the MS program, demonstrating participants' desire to maintain these professional and personal connections in the future. Participants also experienced professional development through these interactions by becoming inspired to attend scientific or teaching conferences in the future.

- Empathy for students

Reentering the student role gave participants more empathy for their own students, which positively impacted their instruction.

- PCK development

Teachers gained content knowledge and pedagogical skill that combined to form improved PCK.

- Content knowledge growth

Gaining content knowledge allowed teachers to bring new topics into their classroom or gain the confidence necessary to teach these topics more effectively. MS program courses exposed and filled gaps in teachers' chemistry content knowledge, which gave them confidence and foundation to include these topics in their curricula.

- Reflection

Participants were able to reflect on their content knowledge and how they present chemistry topics to their students, as well as their teaching philosophy and professional outlook. These opportunities for reflection allowed for professional development.

- Self-perceived growth

Participants perceived growth in themselves as teachers and scientists. Although data supports quantitative changes in teachers' content knowledge and PCK, self-perceived changes are arguably more meaningful in this context.

- Value of the summer campus experience

Teachers were able to be in person while participating in a remote program. While on campus, participants strengthened existing relationships with other teachers and formed connections with SDSU faculty and graduate students. Participants performed lab activities and participated in chemistry laboratory research, which gave them the confidence and experience to implement new lab activities in their own classrooms, thus demonstrating a direct impact of the MS program on their instruction.

Answering the Research Questions

How effectively do courses deepen participants' chemistry content knowledge?

Both the content exam for the narrative study and the chemistry content survey for the program narrative quantitatively demonstrated participants' improved chemistry content knowledge due to participation in MS program content courses. In discussion forums, module surveys, and end-of-semester surveys, MS program participants, including the narrative participant, attributed gains in content understanding to MS program courses. Teachers shared overwhelming qualitative data that they filled gaps in their chemistry content knowledge, as well as learning higher level topics, through the content courses. The narrative participant experienced quantitative and qualitative growth in their chemistry content knowledge. As evidenced through teaching observations and observation surveys, the narrative participant demonstrated their implementation of their enhanced chemistry content knowledge into their instruction. Improvements to their KoSc allowed teachers to improve their overall PCK, and thus their teaching, through the MS program.

How do participants evaluate their own teaching? How do they implement changes in how they teach as a result of this MS program, if at all?

The narrative participant stated that they incorporated new chemistry content into their observed lessons due to MS program courses. They also stated that the summer research experiences inspired them to acquire new laboratory equipment and improve their laboratory teaching approach. Multiple teaching observations took place with the narrative participant and their responses to the observation surveys indicated the steps they have taken to evaluate their own teaching. The CoRe and Teaching Script modules allowed teachers to reflect on their current teaching practice and consider how they would change their instruction based on new PCK gained through MS program courses, especially KoSc, KoT, and KoR.

How does this MS program impact participants' PCK?

The CoRe and Teaching Script modules demonstrated the existence of MS program participants' PCK. Each semester, teachers demonstrated PCK gained through MS program courses. All data collection methods allowed participants to express how they had gained content or pedagogical knowledge through the MS program, demonstrating that the content courses, pedagogical course, action research project, and summer campus experiences all allowed for PCK growth, as well as professional development. PCK changes and implications will be discussed further below.

How do participants learn more about teaching through this MS program?

Through the CHEM 778: Chemistry Teaching Strategies course, teachers gained pedagogical knowledge and skill that they could incorporate into their own teaching. The CHEM 776 course also allowed teachers to carry out laboratory activities from the chemical education literature, which both exposed participants to research-based teaching practices and increased their KoR as a component of PCK. This implementation of activities positively impacted teachers' future laboratory instruction by allowing them to reflect on their current practice and consider how they could make changes in the future. Participants also exchanged resources and teaching strategies with each other through discussion forums, interactions during Zoom meetings and the summer campus experience, and outside of MS program requirements.

How do participants become more effective educators?

By developing PCK, reflecting on their current teaching practice while gaining new knowledge and skills, and experiencing professional development through interactions with each other, MS program participants became more effective educators.

PCK Changes

In Chapter 4, the narrative participant's development of PCK was discussed in detail. Through their two-year experience in the MS program, Taylor developed PCK (N = 380, 43.3%), improved the quality of their PCK by combining knowledge bases (N = 379, 43.2%), experienced professional development (N = 54, 6.2%), and experienced additional PCK and professional development through interactions with other MS program participants, SDSU faculty, and GTAs (*N* = 65, 7.4%). Chapter 5 corroborated these findings by showing that the MS program allowed all participants to develop PCK, improve the quality of their overall PCK, and experience professional development through social interactions.

By improving a single component of their PCK, participants increased the quantity of their overall PCK. A visualization of this concept is given in Figure 5.

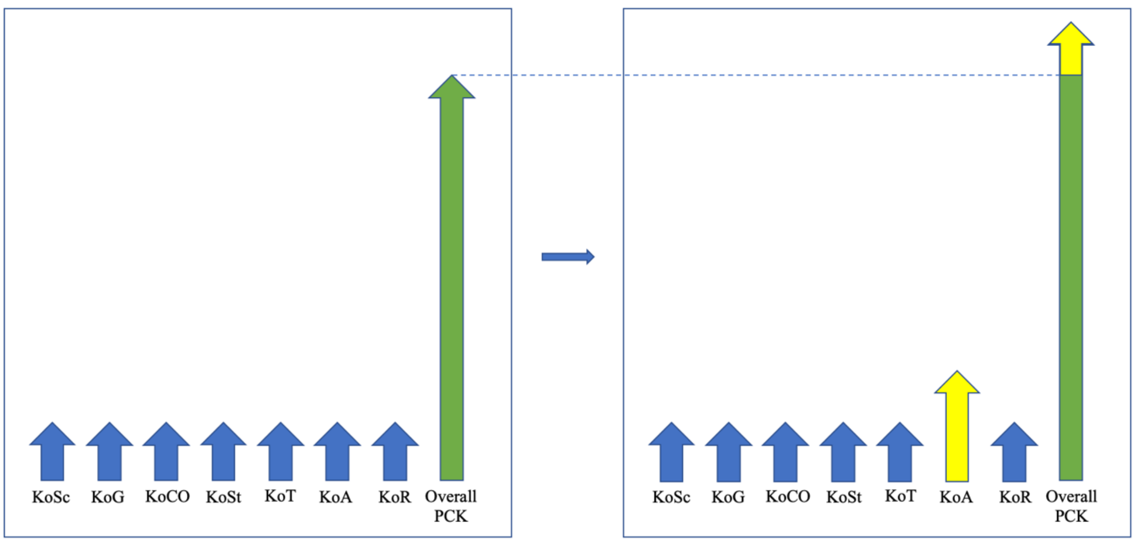


Figure 5. A visualization of increasing a participant's PCK quantity. The blue arrows indicate each of the seven components of PCK, while the green arrow depicts the participant's overall PCK. By increasing one component of PCK (the yellow arrow), the participant's overall PCK increases, thus increasing the quantity of their PCK.

By combining multiple components of PCK, participants increased the quality of their overall PCK. A visualization of this concept is given in Figure 6.

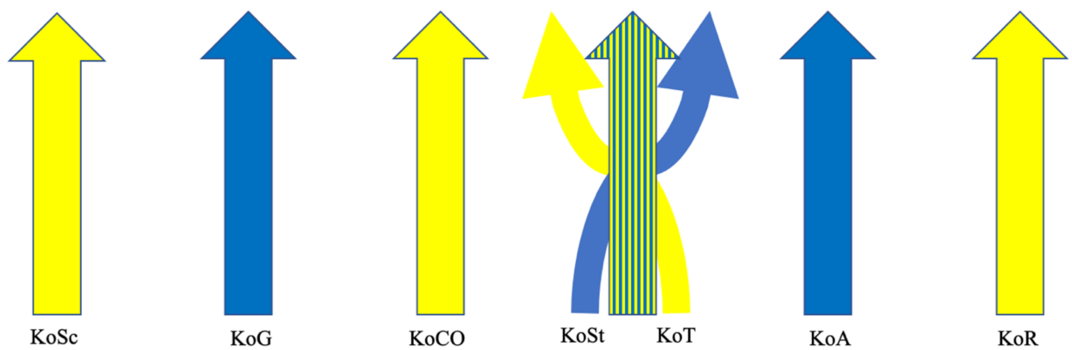


Figure 6. A visualization of increasing a participant's PCK quality. The blue and yellow arrows indicate each of the seven components of PCK. By combining multiple components of PCK (as shown with the yellow and blue striped arrow), the quality of the participant's overall PCK increases.

The interactions between MS program participants demonstrated that PCK can be developed in a social setting. Consistent with the social constructivist framework, MS program participants developed social PCK. By interacting with each other through discussion forums, Zoom meetings, teacher-initiated study sessions, the summer campus experiences, and other means of communication, teachers developed KoSc, KoT, and KoR. These interactions supported positive PCK change. Collaborative learning supports PCK development.[84] Collaborating with other teachers allowed for professional reassurance and reflection, which supported the development of social PCK.[85]

Participants' Focus on Learning, Teaching, and their Students' Learning

In the CoRe and Teaching Script data, there seemed to be levels associated with teachers' ability to focus on their own learning versus their teaching versus their own students' learning. This appeared to depend on their level of content knowledge related to the courses' topics. For example, for courses that were more abstract/challenging, teachers were mainly able to think of the topics in the context of their own learning. The next level up would be to broach the teaching of this topic in their classroom. Once teachers were able to feel confident and supported in their own learning and teaching, they were then able to consider their students' learning. There seemed to be a hierarchy for motivations related to participants' learning to participants' teaching to participants' students' learning. This hierarchy is visualized using Figure 7.

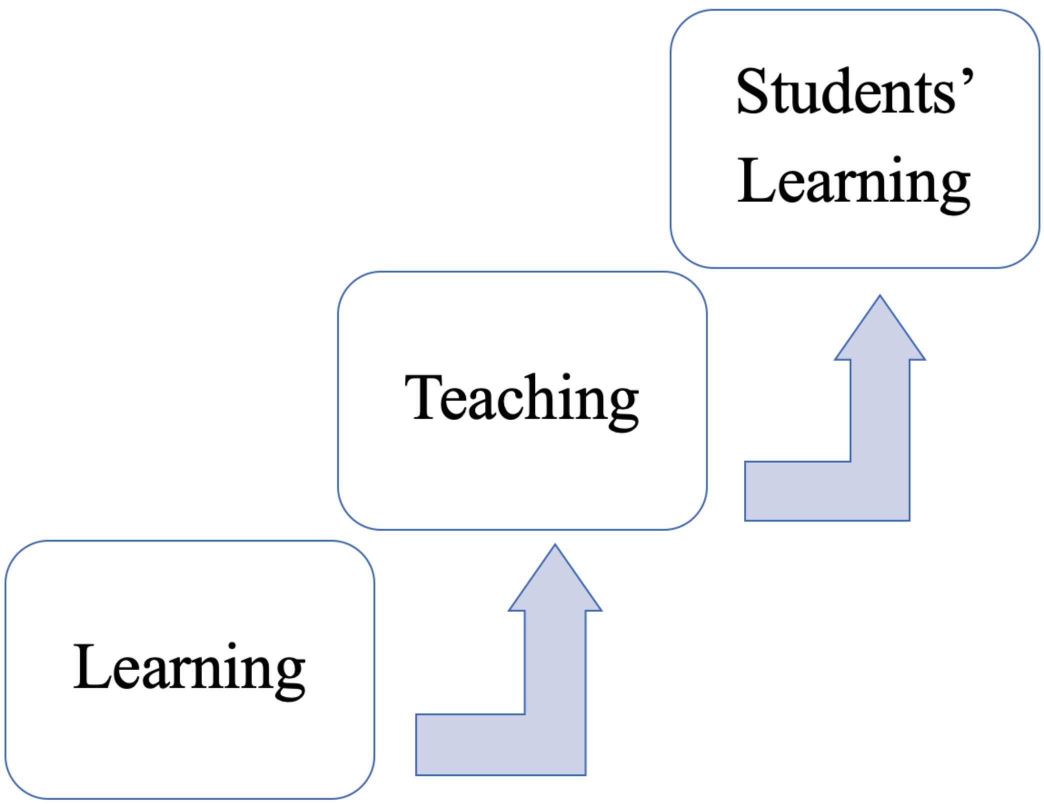


Figure 7. The hierarchy of a participant's focus in terms of MS program impact.

The narrative participant confirmed this hypothesis with the following statement:

- "To me, it's not necessarily a priority thing as much as it is almost like a hierarchy. It's like a prerequisite like, 'I need to know this and then I need to be able to have the skills to be able to teach this, and then based on those things I can affect student learning.'"

Thus, as teachers experience PCK change and professional development, they need to focus on their own learning before applying new knowledge and skills to their teaching. They then would have the ability to improve student learning. Therefore, because the MS program supported participants' learning, the impact of the MS program has the potential to extend to participants' teaching and then their students' learning.

Limitations

For this study, the biggest limitation was time. Because I am the sole researcher on this project, there is only so much data that I could collect and analyze on my own. I collected a great deal of data, as evidenced by previous chapters, but there was so much more that could have been analyzed. As a GTA for the program, I read and evaluated dozens of discussion forum reviews and papers through which teachers described the impact the program has had on their career and their lives. A great deal of feedback was given in these course materials that could not be analyzed due to lack of time and resources. I believe that the trends found in the data I did collect would be consistent with the coursework I didn't analyze, but I know there is a wealth of reflection and feedback that is not presented in this dissertation.

Another limitation is the low participation for case studies. If I were able to follow multiple teachers through the program individually, a clearer picture of the program's impact could have been given. The narrative framework worked well in our case but having multiple individual narrative profiles would have enriched the project and provided more consistency of trends and themes that emerged from the dataset.

My duties as a GTA varied from course to course and instructor to instructor. Because my advisor was an instructor for the program, it worked well logistically to collect more data from the courses they taught, specifically the discussion forums. This was also due to the nature of discussion forums for that course, as they tended to allow for more freedom to reflect, rather than focusing solely on chemistry content.

Moving Forward

The next steps for this study involve discussions of feedback with MS program instructors. Feedback gathered during the two years of this study will inform potential changes to MS program assignments, courses, program logistics, course delivery, and the MS program overall. Feedback from MS program participants was overwhelmingly positive, showing that the MS program is valuable and should continue in the future. The main negative feedback related to the uniformity of MS program courses. MS program instructors should collaborate to establish consistent course delivery and communication across content courses.

Final Thoughts

The MS program enabled its participants to experience professional development and PCK change, which positively impacted their teaching effectiveness and confidence. The MS program offered a unique opportunity for teachers to remain in the classroom while working toward a graduate degree in chemistry. The MS program should continue to offer the summer campus experience, which allows for teachers to gain laboratory research experience and relationships with other science educators. Teachers appreciated the MS program's focus on chemistry content, which supported participants' PCK development. The community support this MS program provided had an immense impact on teachers' professional outlook and teaching confidence.

APPENDIX A: IRB APPROVAL LETTERS

Hello Mary Bautista,

Your application **What Supports Pedagogical Change by Science Teachers? An Assessment of a M.S. in Chemistry Program for Secondary Science Educators** is exempt from further review by the Institutional Review Board of South Dakota State University. Exemption is claimed under exemption criterion 1 outlined in 45 CFR 46, section 104(d).

Note: If the project is changed, it should be re-submitted to the IRB for a determination of whether it still satisfies exemption criteria.

Your approval number is: IRB-2107006-EXM.

I wish you the best in your study.

Sincerely,

Dianne Nagy
Research Integrity and Compliance Officer

Hello Mary Bautista,

The requested change to your protocol **What Supports Pedagogical Change by Science Teachers? An Assessment of a M.S. in Chemistry Program for Secondary Science Educators** has been approved by the IRB.

Please be reminded that as the Principal Investigator, you have ultimate responsibility for the protection of the rights and welfare of human subjects and the ethical conduct of your study. You are responsible for:

- Maintaining valid training in human subjects protection
- Conducting the study using the IRB-approved documents and procedures
- Submitting amendments for changes in the study for IRB review and approval
- Reporting adverse events in a timely manner
- Informing the IRB of any new information in the field of investigation that has bearing on the risks or benefits to subjects in this study
- Maintaining all research records in a secure location
- Formally closing the study via a final report once data collection and engagement with subjects ends

We wish you continued success in your study.

Dianne Nagy

Research Integrity and Compliance Officer

APPENDIX B: NARRATIVE SITE PERMISSION LETTER

Site Permission Letter

Independent School District 719
Prior Lake High School
7575 W. 150th St.

Date: 10/12/2021

Dear SDSU IRB,

Based on my review of the proposed research by Mary Bautista, I give permission for her to conduct the study entitled What Supports Pedagogical Change by Science Teachers? An Assessment of a M.S. in Chemistry Program for Secondary Science Educators within our school district: {Prior Lake High School}. As part of this study, I authorize the researcher to observe teacher instruction through a Zoom recording. The teacher's participation will be voluntary and at their own discretion.

We understand that our organization's responsibilities include allowing video recording of teaching in a live classroom. We reserve the right to withdraw from the study at any time if our circumstances change.

We understand that the research will include observations of typical classroom instruction, focused only on the teacher, over the course of 2 years.

This authorization covers the time period of Fall 2021 to Spring 2023.

I confirm that I am authorized to approve research in this setting.

I understand that the data collected will remain entirely confidential and may not be provided to anyone outside of the research team without permission from the SDSU IRB.

Sincerely,

Authorization Official signature: ____________________

Community Research Partner Name
Community Research Partner Title
Community Research Partner Institution Name
Community Research Partner Contact Information

APPENDIX C: INITIAL SURVEY

1. What is your general science background? What is your chemistry background?
2. What is your background in teaching? Please describe your teacher preparation and teaching experience.
3. On a scale of 1 to 6, how would you rate your effectiveness as a teacher? (Likert) Please explain.
    a. What makes you most effective?
    b. What limits your effectiveness?
4. What was your motivation for teaching high school chemistry/science?
    a. How does this motivation affect you as a science teacher?
    b. How does this motivation impact the level to which you are teaching?
5. How do you determine what a “challenging” concept is in your classroom?
6. On a scale of 1 to 6, how confident do you feel teaching advanced chemistry concepts or concepts that challenge you? (Likert)
    a. Please explain your confidence rating.
7. How comfortable do you feel making changes in how you teach?
    a. If you do make changes, why/how do you decide to make these changes?
8. What are you looking forward to about this program?

APPENDIX D: INITIAL INTERVIEW

1. What is your background in chemistry/science?
    a. Chemistry major, program of study, research
2. What is your background in teaching? Please describe your teacher preparation.
    a. Teacher preparation program, career in teaching
    b. If you were to rate your effectiveness as a teacher, what would it be?
3. What was your motivation for teaching high school chemistry/science?
    a. How does this motivation affect you as a science teacher? Impacts the level to which you are teaching?
4. How confident do you feel teaching advanced chemistry concepts or concepts that challenge you?
    a. How do you determine what a "challenging" concept is in your classroom?
5. How comfortable do you feel making changes in how you teach?
    a. How do you analyze the effects of those changes?
6. What was your motivation for enrolling in this Master's program?
    a. Are you looking to improve your chemistry content knowledge?
    b. Are you looking to improve your teacher pedagogical knowledge?
7. What knowledge do you hope to develop through the program's requirements?
8. What do you hope to gain for your classroom by participating in this program?
    a. How might this make you a more effective teacher?
9. What do you hope to gain personally by participating in this program?

Interviewer reserves the right to ask follow-up questions based on individual responses.

APPENDIX E: CHEMISTRY CONTENT EXAM

Please complete the following questions relating to general chemistry concepts. Your performance on this exam will not impact your standing in the program. I, the researcher, will be the only one to see the results of this exam and it is solely for research purposes to establish a baseline for your chemistry content knowledge. Please complete the surveys following each question regarding your confidence with these topics.

You will have 2 hours to complete this exam. Please do not reference any materials as you take the exam. You may use a calculator as needed. Thank you!

PERIODIC TABLE OF THE ELEMENTS

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 **H** 1.008																	2 **He** 4.00
3 **Li** 6.94	4 **Be** 9.01											5 **B** 10.81	6 **C** 12.01	7 **N** 14.01	8 **O** 16.00	9 **F** 19.00	10 **Ne** 20.18
11 **Na** 22.99	12 **Mg** 24.30											13 **Al** 26.98	14 **Si** 28.09	15 **P** 30.97	16 **S** 32.06	17 **Cl** 35.45	18 **Ar** 39.95
19 **K** 39.10	20 **Ca** 40.08	21 **Sc** 44.96	22 **Ti** 47.87	23 **V** 50.94	24 **Cr** 52.00	25 **Mn** 54.94	26 **Fe** 55.85	27 **Co** 58.93	28 **Ni** 58.69	29 **Cu** 63.55	30 **Zn** 65.38	31 **Ga** 69.72	32 **Ge** 72.63	33 **As** 74.92	34 **Se** 78.97	35 **Br** 79.90	36 **Kr** 83.80
37 **Rb** 85.47	38 **Sr** 87.62	39 **Y** 88.91	40 **Zr** 91.22	41 **Nb** 92.91	42 **Mo** 95.95	43 **Tc** (97)	44 **Ru** 101.1	45 **Rh** 102.91	46 **Pd** 106.42	47 **Ag** 107.87	48 **Cd** 112.41	49 **In** 114.82	50 **Sn** 118.71	51 **Sb** 121.76	52 **Te** 127.60	53 **I** 126.90	54 **Xe** 131.29
55 **Cs** 132.91	56 **Ba** 137.33	57 ***La** 138.91	72 **Hf** 178.49	73 **Ta** 180.95	74 **W** 183.84	75 **Re** 186.21	76 **Os** 190.2	77 **Ir** 192.2	78 **Pt** 195.08	79 **Au** 196.97	80 **Hg** 200.59	81 **Tl** 204.38	82 **Pb** 207.2	83 **Bi** 208.98	84 **Po** (209)	85 **At** (210)	86 **Rn** (222)
87 **Fr** (223)	88 **Ra** (226)	89 **†Ac** (227)	104 **Rf** (267)	105 **Db** (270)	106 **Sg** (271)	107 **Bh** (270)	108 **Hs** (277)	109 **Mt** (276)	110 **Ds** (281)	111 **Rg** (282)	112 **Cn** (285)	113 **Uut** (285)	114 **Fl** (289)	115 **Uup** (288)	116 **Lv** (293)	117 **Uus** (294)	118 **Uuo** (294)

*Lanthanoid Series	58 **Ce** 140.12	59 **Pr** 140.91	60 **Nd** 144.24	61 **Pm** (145)	62 **Sm** 150.4	63 **Eu** 151.97	64 **Gd** 157.25	65 **Tb** 158.93	66 **Dy** 162.50	67 **Ho** 164.93	68 **Er** 167.26	69 **Tm** 168.93	70 **Yb** 173.05	71 **Lu** 174.97
†Actinoid Series	90 **Th** 232.04	91 **Pa** 231.04	92 **U** 238.03	93 **Np** (237)	94 **Pu** (244)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (252)	100 **Fm** (257)	101 **Md** (258)	102 **No** (259)	103 **Lr** (262)

Relevant Equations and Constants for Calculations

Throughout the exam the following symbols have the definitions specified unless otherwise noted.

L, mL	=	liter(s), milliliter(s)	mm Hg	=	millimeters of mercury
g	=	gram(s)	J, kJ	=	joule(s), kilojoule(s)
nm	=	nanometer(s)	V	=	volt(s)
atm	=	atmosphere(s)	mol	=	mole(s)

ATOMIC STRUCTURE

$E = h\nu$

$c = \lambda\nu$

E = energy

ν = frequency

λ = wavelength

Planck's constant, $h = 6.626 \times 10^{-34}$ J s

Speed of light, $c = 2.998 \times 10^{8}$ m s^{-1}

Avogadro's number $= 6.022 \times 10^{23}$ mol^{-1}

Electron charge, $e = -1.602 \times 10^{-19}$ coulomb

EQUILIBRIUM

$$K_c = \frac{[\mathrm{C}]^c[\mathrm{D}]^d}{[\mathrm{A}]^a[\mathrm{B}]^b}, \text{ where } a\,\mathrm{A} + b\,\mathrm{B} \rightleftarrows c\,\mathrm{C} + d\,\mathrm{D}$$

$$K_p = \frac{(P_{\mathrm{C}})^c(P_{\mathrm{D}})^d}{(P_{\mathrm{A}})^a(P_{\mathrm{B}})^b}$$

$$K_a = \frac{[\mathrm{H}^+][\mathrm{A}^-]}{[\mathrm{HA}]}$$

$$K_b = \frac{[\mathrm{OH}^-][\mathrm{HB}^+]}{[\mathrm{B}]}$$

$$K_w = [\mathrm{H}^+][\mathrm{OH}^-] = 1.0 \times 10^{-14} \text{ at } 25^\circ\mathrm{C}$$

$$= K_a \times K_b$$

$$\mathrm{pH} = -\log[\mathrm{H}^+],\ \mathrm{pOH} = -\log[\mathrm{OH}^-]$$

$$14 = \mathrm{pH} + \mathrm{pOH}$$

$$\mathrm{pH} = \mathrm{p}K_a + \log\frac{[\mathrm{A}^-]}{[\mathrm{HA}]}$$

$$\mathrm{p}K_a = -\log K_a,\ \mathrm{p}K_b = -\log K_b$$

Equilibrium Constants

K_c (molar concentrations)

K_p (gas pressures)

K_a (weak acid)

K_b (weak base)

K_w (water)

KINETICS

$$\ln[\mathrm{A}]_t - \ln[\mathrm{A}]_0 = -kt$$

$$\frac{1}{[\mathrm{A}]_t} - \frac{1}{[\mathrm{A}]_0} = kt$$

$$t_{1/2} = \frac{0.693}{k}$$

k = rate constant

t = time

$t_{1/2}$ = half-life

GASES, LIQUIDS, AND SOLUTIONS

$$PV = nRT$$

$$P_A = P_{\text{total}} \times X_A, \text{ where } X_A = \frac{\text{moles A}}{\text{total moles}}$$

$$P_{total} = P_A + P_B + P_C + \ldots$$

$$n = \frac{m}{\boldsymbol{M}}$$

$$\text{K} = {}^\circ\text{C} + 273$$

$$D = \frac{m}{V}$$

$$KE \text{ per molecule} = \frac{1}{2} mv^2$$

$$\text{Molarity, } M = \text{moles of solute per liter of solution}$$

$$A = abc$$

P = pressure
V = volume
T = temperature
n = number of moles
m = mass
$\boldsymbol{M}$ = molar mass
D = density
KE = kinetic energy
v = velocity
A = absorbance
a = molar absorptivity
b = path length
c = concentration

Gas constant, R = 8.314 J mol^{-1} K^{-1}
= 0.08206 L atm mol^{-1} K^{-1}
= 62.36 L torr mol^{-1} K^{-1}

1 atm = 760 mm Hg = 760 torr

STP = 273.15 K and 1.0 atm

Ideal gas at STP = 22.4 L mol^{-1}

THERMODYNAMICS / ELECTROCHEMISTRY

$$q = mc\Delta T$$

$$\Delta S^\circ = \sum S^\circ \text{ products} - \sum S^\circ \text{ reactants}$$

$$\Delta H^\circ = \sum \Delta H_f^\circ \text{ products} - \sum \Delta H_f^\circ \text{ reactants}$$

$$\Delta G^\circ = \sum \Delta G_f^\circ \text{ products} - \sum \Delta G_f^\circ \text{ reactants}$$

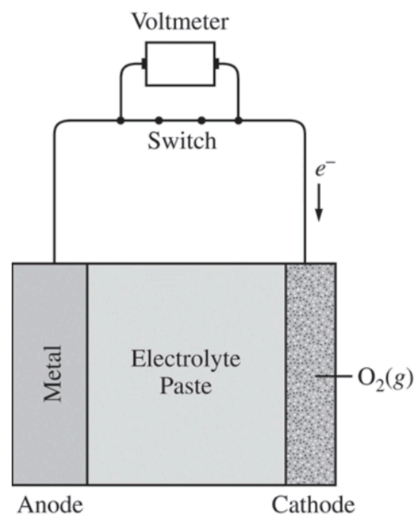
$$\begin{aligned} \Delta G^\circ &= \Delta H^\circ - T\Delta S^\circ \\ &= -RT \ln K \\ &= -nFE^\circ \end{aligned}$$

$$I = \frac{q}{t}$$

q = heat
m = mass
c = specific heat capacity
T = temperature
S° = standard entropy
H° = standard enthalpy
G° = standard Gibbs free energy
n = number of moles
E° = standard reduction potential
I = current (amperes)
q = charge (coulombs)
t = time (seconds)

Faraday's constant, F = 96,485 coulombs per mole of electrons

$$1 \text{ volt} = \frac{1 \text{ joule}}{1 \text{ coulomb}}$$



1. Metal-air cells are a relatively new type of portable energy source consisting of a metal anode, an alkaline electrolyte paste that contains water, and a porous cathode membrane that lets in oxygen from the air. A schematic of the cell is shown above. Reduction potentials for the cathode and three possible metal anodes are given in the table below.

Half Reaction	*E* at pH 11 and 298 K (V)
$O_2(g) + 2\,H_2O(l) + 4\,e^- \rightarrow 4\,OH^-(aq)$	+0.34
$ZnO(s) + H_2O(l) + 2\,e^- \rightarrow Zn(s) + 2\,OH^-(aq)$	−1.31
$Na_2O(s) + H_2O(l) + 2\,e^- \rightarrow 2\,Na(s) + 2\,OH^-(aq)$	−1.60
$CaO(s) + H_2O(l) + 2\,e^- \rightarrow Ca(s) + 2\,OH^-(aq)$	−2.78

a) Early forms of metal-air cells used zinc as the anode. Zinc oxide is produced as the cell operates according to the overall equation below.

$$2\,Zn(s) + O_2(g) \rightarrow 2\,ZnO(s)$$

i) Using the data in the table above, calculate the cell potential for the zinc-air cell.

ii) The electrolyte paste contains OH^- ions. On a copy of the diagram of the cell above, draw an arrow to indicate the direction of migration of OH^- ions through the electrolyte as the cell operates.

b) A fresh zinc-air cell is weighed on an analytical balance before being placed in a hearing aid for use.

i) As the cell operates, does the mass of the cell increase, decrease, or remain the same?

ii) Justify your answer to part (b)(i) in terms of the equation for the overall cell reaction.

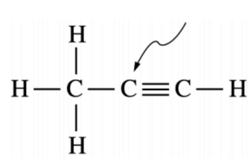
How comfortable do you feel with the topics presented in this problem?

Not comfortable at all 1 2 3 4 5 6 Very comfortable

How confident do you feel with the accuracy of your answer?

Not confident at all 1 2 3 4 5 6 Very confident

2. Given the structural formula for propyne below,



a) Indicate the hybridization of the carbon atom indicated by the arrow in the structure above;

b) Indicate the total number of sigma (σ) bonds and the total number of pi (π) bonds in the molecule.

How comfortable do you feel with the topics presented in this problem?

Not comfortable at all 1 2 3 4 5 6 Very comfortable

How confident do you feel with the accuracy of your answer?

Not confident at all 1 2 3 4 5 6 Very confident

$$2\,NO(g) + Br_2(g) \rightarrow 2\,NOBr(g)$$

3. A rate study of the reaction represented above was conducted at 25°C. The data that were obtained are shown in the table below.

Experiment	Initial [NO] (mol L^{-1})	Initial [Br_2] (mol L^{-1})	Initial Rate of Appearance of NOBr (mol L^{-1} s^{-1})
1	0.0160	0.0120	3.24×10^{-4}
2	0.0160	0.0240	6.38×10^{-4}
3	0.0320	0.0060	6.42×10^{-4}

a) Calculate the initial rate of disappearance of $Br_2(g)$ in experiment 1.

b) Determine the order of the reaction with respect to each reactant, $Br_2(g)$ and $NO(g)$. In each case, explain your reasoning.

c) For the reaction,

i. write the rate law that is consistent with the data, and

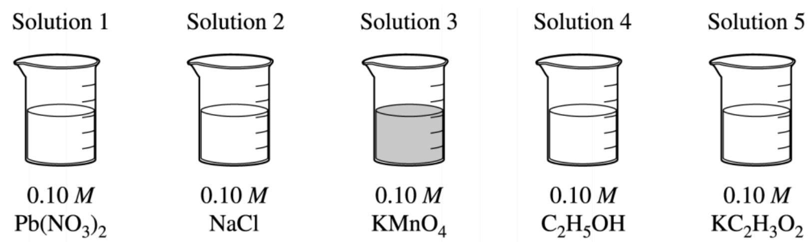
ii. calculate the value of the specific rate constant, *k*, and specify units.

How comfortable do you feel with the topics presented in this problem?

Not comfortable at all 1 2 3 4 5 6 Very comfortable

How confident do you feel with the accuracy of your answer?

Not confident at all 1 2 3 4 5 6 Very confident



4. Answer the questions below that relate to the five aqueous solutions at 25°C shown above.

a) Which solution has the highest boiling point? Explain.

b) Which solution has the highest pH? Explain.

c) Identify a pair of the solutions that would produce a precipitate when mixed together. Write the formula of the precipitate.

d) Which solution could be used to oxidize the $Cl^{-}(aq)$ ion? Identify the product of the oxidation.

e) Which solution would be the least effective conductor of electricity? Explain.

How comfortable do you feel with the topics presented in this problem?

Not comfortable at all 1 2 3 4 5 6 Very comfortable

How confident do you feel with the accuracy of your answer?

Not confident at all 1 2 3 4 5 6 Very confident

5. Suppose that a stable element with atomic number 119, symbol Q, has been discovered.

a) Write the ground-state electron configuration for Q, showing only the valence-shell electrons.
b) Would Q be a metal or a nonmetal? Explain in terms of electron configuration.
c) On the basis of periodic trends, would Q have the largest atomic radius in its group or would it have the smallest? Explain in terms of electronic structure.
d) What would be the most likely charge of the Q ion in stable ionic compounds?
e) Write a balanced equation that would represent the reaction of Q with water.

How comfortable do you feel with the topics presented in this problem?

Not comfortable at all 1 2 3 4 5 6 Very comfortable

How confident do you feel with the accuracy of your answer?

Not confident at all 1 2 3 4 5 6 Very confident

$$NaHCO_3(s) + HC_2H_3O_2(aq) \rightarrow NaC_2H_3O_2(aq) + H_2O(l) + CO_2(g)$$

6. A student designs an experiment to study the reaction between $NaHCO_3$ and $HC_2H_3O_2$. The reaction is represented by the equation above. The student places 2.24 g of $NaHCO_3$ in a flask and adds 60.0 mL of 0.875 *M* $HC_2H_3O_2$. The student observes the formation of bubbles and that the flask gets cooler as the reaction proceeds.

   a) Identify the reaction represented above as an acid-base reaction, precipitation reaction, or redox reaction. Justify your answer.

   b) The student observes that the bubbling is rapid at the beginning of the reaction and gradually slows as the reaction continues. Explain this change in the reaction rate in terms of the collisions between reactant particles.

   c) In thermodynamic terms, a reaction can be drive by enthalpy, entropy, or both.

      i) Considering that the flask gets cooler as the reaction proceeds, what drives the chemical reaction between $NaHCO_3(s)$ and $HC_2H_3O_2(aq)$? Answer by drawing a circle around on of the choices below.

      Enthalpy only Entropy only Both enthalpy and entropy

      ii) Justify your selection in part (d)(i) in terms of $\Delta G°$.

How comfortable do you feel with the topics presented in this problem?

Not comfortable at all 1 2 3 4 5 6 Very comfortable

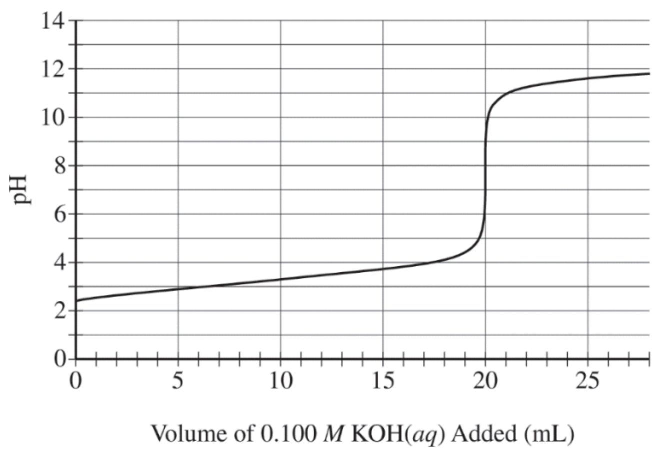
How confident do you feel with the accuracy of your answer?

Not confident at all 1 2 3 4 5 6 Very confident

7. To produce an aqueous solution of HNO_2, the student bubbles $N_2O_3(g)$ into distilled water. Assume that the reaction goes to completion and that HNO_2 is the only species produced. To determine the concentration of $HNO_2(aq)$ in the resulting solution, the student titrates a 100. mL sample of the solution with 0.100 *M* KOH(*aq*). The neutralization reaction is represented below.

$$HNO_2(aq) + OH^-(aq) \rightarrow NO_2^-(aq) + H_2O(l)$$

The following titration curve shows the change in pH of the solution during the titration.



a) Use the titration curve and the information above to

i. determine the initial concentration of the $HNO_2(aq)$ solution

ii. estimate the value of pK_a for $HNO_2(aq)$

b) During the titration, after a volume of 15 mL of 0.100 *M* KOH(*aq*) has been added, which species, HNO_2(*aq*) or NO_2^-(*aq*), is present at a higher concentration in the solution? Justify your answer.

How comfortable do you feel with the topics presented in this problem?

Not comfortable at all 1 2 3 4 5 6 Very comfortable

How confident do you feel with the accuracy of your answer?

Not confident at all 1 2 3 4 5 6 Very confident

$$2\,Fe(s) + \frac{3}{2}\,O_2(g) \rightarrow Fe_2O_3(s) \qquad \Delta H_f^\circ = -824 \text{ kJ mol}^{-1}$$

8. Iron reacts with oxygen to produce iron(III) oxide, as represented by the equation above. A 75.0 g sample of Fe(*s*) is mixed with 11.5 L of O_2(*g*) at 2.55 atm and 298 K.
   a) Calculate the number of moles of each of the following before the reaction begins.
      i. Fe(*s*)
      ii. O_2(*g*)
   b) Identify the limiting reactant when the mixture is heated to produce Fe_2O_3(*s*). Support your answer with calculations.

c) Calculate the number of moles of $Fe_2O_3(s)$ produced when the reaction proceeds to completion.

d) The standard free energy of formation, $\Delta G°_f$, of $Fe_2O_3(s)$ is -740. kJ mol^{-1} at 298 K.

i. Calculate the standard entropy of formation, $\Delta S°_f$, of $Fe_2O_3(s)$ at 298 K. Include units with your answer.

ii. Which is more responsible for the spontaneity of the formation reaction at 298 K, the standard enthalpy of formation, $\Delta H°_f$, of the standard entropy of formation, $\Delta S°_f$? Justify your answer.

The reaction represented below also produces iron(III) oxide. The value of $\Delta H°$ for the

reaction is -280. kJ per mole of $Fe_2O_3(s)$ formed.

$$2\ FeO(s) + \tfrac{1}{2}\ O_2(g) \rightarrow 2\ Fe_2O_3(s)$$

e) Calculate the standard enthalpy of formation, $\Delta H°_f$, of $FeO(s)$.

How comfortable do you feel with the topics presented in this problem?

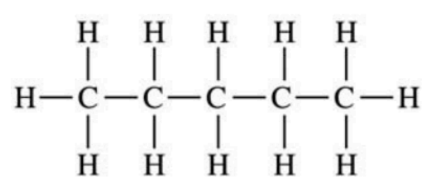
Not comfortable at all 1 2 3 4 5 6 Very comfortable

How confident do you feel with the accuracy of your answer?

Not confident at all 1 2 3 4 5 6 Very

confident

9. The structural formula of one isomer of pentane is shown below. Draw the structural formulas for the other two isomers of pentane. Be sure to include all atoms of hydrogen and carbon in your structures.



How comfortable do you feel with the topics presented in this problem?

Not comfortable at all 1 2 3 4 5 6 Very

comfortable

How confident do you feel with the accuracy of your answer?

Not confident at all 1 2 3 4 5 6 Very

confident

APPENDIX F: CHECK-IN INTERVIEWS

1. Could you describe where you’re at in terms of program requirements? (Courses, research, etc.)
2. How is the semester going so far for you?
3. How is this program helping you make progress toward your goals?
4. What are your hopes for the semester? What do you hope to gain this semester?
5. Are there any concerns you have about the program?
6. Discuss recent surveys, interviews, or journal responses.

Interviewer reserves the right to ask follow-up questions based on individual responses.

APPENDIX G: PRE- AND POST-OBSERVATION SURVEYS

Pre-Observation Survey

Before Observation

1. What lesson will you be teaching?
2. How do you feel about the lesson that will be observed?
3. What kinds of things did you take into consideration in planning this lesson?
    a. Is there anything new that you are adding to this lesson? If so, why did you decide to change this lesson?
4. How do you anticipate your students will receive this lesson?
5. Do you feel confident teaching this lesson? Why or why not?

Post-Observation Survey

After Observation

1. How do you feel the observed lesson went?
    a. How confident are you that students learned? Please explain.
    b. Did the lesson go as expected? Why or why not?
    c. Would you repeat this lesson the same way in the future?
2. How did your students receive this lesson?
    a. Did your students understand the material? How do you know?
    b. Did you notice any confusion or misconceptions? How did you notice?

APPENDIX H: EXIT SURVEY

1. On a scale of 1 to 6, how would you rate your effectiveness as a teacher? (Likert) Please explain your effectiveness rating.
2. If any, what knowledge or skills did you gain in this program to become a **more effective teacher**?
3. If any, what knowledge or skills did you gain in this program to become a **better scientist**?
4. Has your motivation for teaching high school science changed as a result of this MS program? Why or why not?
5. Have you made changes to your teaching as a result of the MS program? If so, do you think these changes have improved your teaching?
6. How did the MS program help you achieve your goals?
7. What did you find **most** valuable about the MS program?
8. What did you find **least** valuable about the MS program?
9. Are you glad you chose to complete this program? Why or why not?
10. Please share any final thoughts you have about the MS program, if not already discussed above.

APPENDIX I: EXIT INTERVIEW

1. Follow up on responses to exit survey
   a. What impact did this program have on you as a teacher? Professionally? Personally?
   b. Ask about overall thoughts about program

Interviewer reserves the right to ask follow-up questions based on individual responses.

APPENDIX J: DISCUSSION FORUM QUESTIONS

- How has this course impacted how you teach atomic theory/quantum theory/periodic trends?
- What, if anything, have you taken away from discussion forums to use in your classroom in the future?
- What changes have you made to your teaching so far this semester, if at all?
- If you did make changes, how did it go in your classroom? How did your students respond to these changes? How did you feel the changes impacted your teaching effectiveness?
- If you haven't made any changes to your teaching, what changes would you consider making? Why?

APPENDIX K: MIDWAY COURSE REFLECTION (CHEM 778)

- How have topics from this course impacted you or your teaching?
- How have you utilized ideas from this course in your classroom?

APPENDIX L: CONTENT REPRESENTATION (CORE)

Module: Content Representation (CoRe)

How do I get started?

There will be a discussion forum open on D2L where you will post what you find to be the most challenging concept for the week. You will be required to make a post each week to demonstrate participation. In the final week, you will make a post choosing the most challenging concept from the four weeks.

What is the goal of this module?

In this module, you will create a Content Representation, or CoRe, on the most challenging concept you have chosen. A CoRe is a representation of science teachers' understanding or conceptualization of "big ideas" in a specific content area (Loughran et al., 2004). Designing a content representation will allow you to think about the challenging concept you have chosen in terms of your own teaching.

How do I create a Content Representation (CoRe)?

To create a CoRe, read the following prompt and complete the table below with bullet points or full sentences. Consider the following scenario:

> You will teach the concept you have chosen to your own students, but in a course in which this topic is appropriate. For example, if the concept would not typically be taught in a class you currently teach, imagine you are teaching a higher level

course where teaching the concept makes sense. You may not be teaching this topic currently, but you may in the future.

CoRe Prompting Questions	**Your Response**
Which concept would be most challenging for you to teach? Why?	
Class to which you would teach this concept.	
Which standard(s) relate most closely to this concept?	

What you intend the students to learn about this idea.	
Why it is important for students to know this.	
What else you know about this idea (that you do not intend students to know yet).	
Difficulties/limitations connected with teaching this idea.	

Knowledge about students' thinking which influences your teaching of this idea.	
Other factors that influence your teaching of this idea.	
Teaching procedures (and particular reasons for using these to engage with this idea).	

Specific ways of ascertaining students' understanding or confusion around this idea (include likely range of responses).	

Reference

Loughran, J.; Mulhall, P.; Berry, A. In Search of Pedagogical Content Knowledge in Science: Developing Ways of Articulating and Documenting Professional Practice. *J. Res. Sci. Teach.* **2004**, *41*, 370-391.

Rubric

Expected Behavior	0 pts	2 pts	3 pts	4 pts
Discussion Forum Components				
Posting Opinion on Most Challenging Topic – Once Each Week from Units X-XX	Did not post to Discussion Forum	Posted opinion and explained why in only 1 of the 3 weeks	Posted opinion and explained why in 2 of the 3 weeks	Posted opinion and explained why in weeks 1, 2, & 3
Choosing Most Challenging Concept in Week 4 of Discussion Forum (either a 0 or 2 for a score)	Did not identify most challenging concept	Identified most challenging concept		

Responding to other posts with arguments as to the challenge (purely the number of posts)	None over the total of 4 weeks	One over the total of 4 weeks	2 or 3 over the total of 4 weeks	4 or more over the total of 4 weeks
CoRe Components				
Completing the Content Representation (CoRe) Table (either a 0 or 2 for a score)	Did not complete CoRe	Completed CoRe		
Student Knowledge - Intentions for student learning - Importance of learning concept	Little to no information provided	Some detail is provided regarding intentions for student learning and importance	1 of the 2 components is addressed in extensive detail	Intentions for student learning and importance are addressed in extensive detail

Additional Knowledge Beyond What Students Need - Additional knowledge - Difficulties/limitations	Little to no information provided	Some detail is provided regarding additional knowledge and difficulties	1 of the 2 components is addressed in extensive detail	Additional knowledge and teaching limitations are addressed in extensive detail
Context Factors - Student learning context - Relevant standards - Knowledge about students' thinking - Factors influencing teaching	Little to no information provided	Only 1 component is addressed with strong detail, with limited information on other topics	2-3 of the 4 components are addressed with strong detail	All components are addressed with extensive detail

Pedagogy and Assessment - Teaching procedures - Assessing student understanding or confusion	Little to no information provided	Some detail is provided regarding teaching procedures and assessment	1 of the 2 components is addressed in extensive detail	Teaching procedures and assessment of student understanding are addressed in extensive detail
Technical Components				
Completing Survey Portion of Module (either a 0 or 2 for a score)	Did not complete survey	Completed survey		
Grammar and Form	Multiple errors in grammar and spelling	Very few errors in grammar and spelling		

APPENDIX M: TEACHING SCRIPT

Module: Teaching Script

please submit an organizational method (such as slides) along with your completed table and teaching script

How do I get started?

There will be a discussion forum open on D2L where you will post what you find to be the most challenging concept for the week. You will be required to make a post each week to demonstrate participation. In the final week, you will make a post choosing the <u>most challenging concept</u> from the four weeks.

What is the goal of this module?

In this module, you will create a teaching script based on a given teaching situation. Creating a teaching script will allow you to practice preparing information about a concept and anticipating your students' response to instruction.

<u>Write a teaching script as if it were a script for a one-act play.</u>

- A play contains words that will be said (lines)
- A play contains stage directions
    - Nonverbal information about peoples' actions
    - Expected behavior and responses from characters and audience

        - Nonverbal information about the setting/scene

- A play contains scenery/a set

        - PowerPoint to provide context or other preferred organizational methods

How do I create a teaching script?

To create a teaching script, read the following prompt and complete the table below with bullet points or full sentences. Then, using the information from the table, write a teaching script for your challenging concept, which should include PowerPoint slides or other preferred organizational method. Consider the following scenario:

> Imagine you are teaching students at a level at which topic makes sense
>
> Your objective is to create a teaching script for yourself that, if scripted enough, could be used to effectively communicate the concept. Think of a teaching script as if it were a script for a theatrical play. Your teaching script could be used as notes to guide your teaching or could be followed by a substitute teacher (your "understudy") if you were not present to teach the concept.

What would be your teaching script?

- Attempt to describe your teaching script in as much detail as possible, taking into consideration information from the table.
- **Your teaching script should explain exactly what you would tell your students, as if the teaching script were a transcript of your instruction.**

- Also include in your script information you might not say, but information that supports your script or ideas.

To create the script, consider the following background questions to create an outline:

Teaching Script Background Questions	**Your Response**
Which concept would be most challenging for you to teach? Why?	
To which class would you teach this concept?	

How does this concept tie into what you are teaching at your current level or into an idea (if you don't currently teach it)? Which standard(s) relate most closely to this topic?	

Why is it important for students to understand this concept? *Is there a real-world connection for students?*	
What teaching strategies or pedagogical tools would you use when teaching this concept? *What would the timeline look like for teaching this concept?*	

What prior knowledge do you have about this concept? *From this knowledge, what do your students need to know about this concept at this moment in time?* *What do you believe are the fundamental components of the concept?*	

What additional information for the more curious do you need to support your teaching script?	
What materials could you provide if students want to learn more about this concept?	

What misconceptions would you expect to come up during this lesson? How would you address these misconceptions?	
What follow-up questions may arise due to this lesson? What reactions from students do you expect? Give examples based on past experiences.	

From the information you have completed in the table, write your teaching script in as much detail as possible (not all information from the table needs to be present in the script, but can serve as background information to reference if needed):

Rubric

Expected Behavior	**0 pts**	**2 pts**	**3 pts**	**4 pts**
Discussion Forum Components				
Posting Opinion on Most Challenging Topic – Once Each Week from Units X-XX	Did not post to Discussion Forum	Posted opinion and explained why in only 1 of the 3 weeks	Posted opinion and explained why in 2 of the 3 weeks	Posted opinion and explained why in weeks 1, 2, & 3
Choosing Most Challenging Concept in Week 4 of Discussion Forum (either a 0 or 2 for a score)	Did not identify most challenging concept	Identified most challenging concept		
Responding to other posts with arguments as to the challenge (purely the number of posts)	None over the total of 4 weeks	One over the total of 4 weeks	2 or 3 over the total of 4 weeks	4 or more over the total of 4 weeks
Teaching Script Components				

Completing the Teaching Script (either a 0 or 2 for a score)	Did not complete teaching script	Completed teaching script		
Details of Your Prior Knowledge of Concept	Little to no information provided	Some detail is provided regarding prior knowledge of this concept	Good, basic information outlining knowledge of this concept	Excellent, detailed account of knowledge of this concept
Additional Information Beyond What Students Need - Additional information - Supplemental materials - Follow-up questions	Little to no information provided	Only 1 component is addressed with strong detail, with limited information on other topics	2 of the 3 components are addressed with strong detail	All components are addressed with extensive detail

Context Factors - Student learning context - Relevant standards - Teaching connections - Real-world examples	Little to no information provided	Only 1 component is addressed with strong detail, with limited information on other topics	2-3 of the 4 components are addressed with strong detail	All components are addressed with extensive detail
Pedagogy and Assessment - Teaching strategies - Misconceptions	Little to no information provided	Some detail is provided regarding pedagogy and assessment	1 of the 2 components is addressed in extensive detail	Teaching strategies and misconceptions are addressed in extensive detail
Technical Components				
Completing Survey Portion of Module (either a 0 or 2 for a score)	Did not complete survey	Completed survey		

Creating an organizational method (such as PowerPoint)	None used	A method was used	[redacted]
Grammar and Form	Multiple errors in grammar and spelling	Very few errors in grammar and spelling	[redacted]

APPENDIX N: MODULE SURVEY

What was your experience completing this module?

- *Please complete this brief survey to give feedback about this module and provide thoughts on your experience creating a Content Representation (CoRe)/Teaching Script.*

1. Was it challenging to create a Content Representation (CoRe)/Teaching Script for this concept? Explain.

2. Would you feel comfortable teaching this concept without preparing beforehand? Why or why not?

3. On a scale of 1 to 6, how confident would you be teaching this concept?

   Low level of confidence 1 2 3 4 5 6 *High level of confidence*

   - What would make you feel more confident teaching this concept?

4. How has the content of this course impacted your Content Representation (CoRe)/Teaching Script?
5. How has this module transformed your teaching of this concept, if at all?

APPENDIX O: SUMMER JOURNAL PROMPTS

Summer Journal #1

1. What are some goals you have for yourself while you are on campus?
2. What do you hope to gain through this experience as a teacher? What do you hope to gain as a scientist?
3. If this is your first summer on campus, what do you think it will be like in the lab? If you are returning to campus, how have your past experiences at SDSU impacted your thoughts about this summer?
4. What are some other thoughts, feelings, or concerns you have before arriving on campus? (about the program, the summer courses, the laboratory component, etc.)

Summer Journal #2

1. What is it like being in your assigned research lab? Was it what you expected?
2. How has the summer research experience been meaningful to you so far as a teacher? As a scientist?
3. How have the summer courses been meaningful to you so far?
4. What are some other thoughts, feelings, or concerns you have after one week on campus? (about the program, the summer courses, the laboratory component, etc.)

Summer Journal #3

1. How have you grown professionally through this summer experience?
2. What networking opportunities have arisen through being on campus?

3. What will you take away from this summer research experience as a teacher? As a scientist?
4. Did you meet the goals you had for yourself? Did the campus research experience meet your expectations? Please explain.
5. If this was your first summer on campus, how did it go? What was your experience like? If this was your second summer on campus, how did this summer compare to your previous experience?
6. What are some other thoughts, feelings, or concerns you have after your two weeks on campus? (about the program, the summer courses, the laboratory component, etc.)

APPENDIX P: CHEMISTRY CONTENT SURVEY

1. Answer the following questions that relate to the chemistry of halogen oxoacids.

   a. Use the information in the table below to answer part (a)(i).

Acid	K_a at 298 K
HOCl	2.9×10^{-8}
HOBr	2.4×10^{-9}

      i. Which of the two acids is stronger, HOCl or HOBr? Justify your answer in terms of K_a.

      ii. Draw a complete Lewis electron-dot diagram for the acid that you identified in part (a)(i).

      iii. Hypoiodous acid has the formula HOI. Predict whether HOI is a stronger acid or a weaker acid than the acid that you identified in part (a)(i). Justify your prediction in terms of chemical bonding.

   b. Write the equation for the reaction that occurs between hypochlorous acid and water.

   c. A buffer solution is prepared by dissolving some solid NaOCl in a solution of HOCl at 298 K. The pH of the buffer solution is determined to be 6.48.

      i. Calculate the value of $[H_3O^+]$ in the buffer solution.

      ii. Indicate which of the HOCl(*aq*) or OCl^-(*aq*) is present at the higher concentration in the buffer solution. Support your answer with a calculation.

2. An environmental concern is the depletion of O_3 in Earth's upper atmosphere, where O_3 is normally in equilibrium with O_2 and O. A proposed mechanism for the depletion of O_3 in the upper atmosphere is shown below.

Step I	$O_3 + Cl \rightarrow O_2 + ClO$
Step II	$ClO + O \rightarrow Cl + O_2$

   a. If the rate law for the overall reaction is found to be *rate* = $k[O_3][Cl]$, determine the following.

      i. The overall order of the reaction

      ii. Appropriate units for the rate constant, k

      iii. The rate-determining step of the reaction, along with justification for your answer

Compound Name	Compound Formula
Propane	$CH_3CH_2CH_3$
Propanone	CH_3COCH_3
1-propanol	$CH_3CH_2CH_2OH$

3. Using the information in the table above, answer the following questions about organic compounds.

   a. For propanone,

      i. Draw the complete structural formula (showing all atoms and bonds);

      ii. Predict the approximate carbon-to-carbon-to-carbon bond angle.

b. Draw the complete structural formula for an isomer of the molecule you drew in part a(i).

APPENDIX Q: END-OF-SEMESTER SURVEY

We would like to learn more about your experience in the M.S. Chemistry program this semester. Please answer the following questions in as much detail as possible. Thank you!

1. Rate the following aspects of content courses as being meaningful to you as a *teacher*: (Likert 1-6)
    i. Discussion Forums
    ii. Homework Sets
    iii. Modules
    iv. Exams
    v. Other: list additional item
2. Rate the following aspects of content courses as being meaningful to you as a *learner*: (Likert 1-6)
    i. Discussion Forums
    ii. Homework Sets
    iii. Modules
    iv. Exams
    v. Other: list additional item
3. Please explain why certain aspects of content courses were meaningful to you.
4. Please explain why certain aspects of content courses were *not* meaningful to you.

5. How would you rate the overall benefit of the course(s) you took this semester? (Was taking the course beneficial?) (Likert 1-6)
    i. List possible courses from the semester
6. Please explain your rating of how the course(s) benefitted you:
7. How would you rate the value for money of the course(s) you took this semester? (Was taking the course "worth it"?) (Likert 1-6)
    i. List possible courses from the semester.
8. Please explain your rating of each course's value for money:
9. What, if anything, has not met your expectations about the program?
10. What, if anything, has exceeded your expectations about the program?
11. What would you change to improve the program?
12. How has your chemistry content knowledge changed this semester?
13. How has your pedagogical skill changed this semester?
14. Besides chemistry knowledge and pedagogical skill, what else have you gained as a teacher as a result of this program this semester?
15. How have you become more effective as a teacher this semester?
16. Please leave any other comments, thoughts, or concerns about your time in the program so far that otherwise have not been expressed in this survey:

APPENDIX R: ATTITUDE TOWARD SUBJECT OF CHEMISTRY INVENTORY

Attitude toward Subject of Chemistry Inventory (ASCI) (Adapted from Bauer, 2008).

CHEMISTRY LABORATORY RESEARCH IS

1. easy |__1__|__2__|__3__|__4__|__5__|__6__|__7__| hard

middle

2. worthless |__1__|__2__|__3__|__4__|__5__|__6__|__7__| beneficial
3. exciting |__1__|__2__|__3__|__4__|__5__|__6__|__7__| boring
4. complicated |__1__|__2__|__3__|__4__|__5__|__6__|__7__| simple
5. confusing |__1__|__2__|__3__|__4__|__5__|__6__|__7__| clear
6. good |__1__|__2__|__3__|__4__|__5__|__6__|__7__| bad

middle

7. satisfying |__1__|__2__|__3__|__4__|__5__|__6__|__7__| frustrating
8. scary |__1__|__2__|__3__|__4__|__5__|__6__|__7__| fun
9. comprehensible |__1__|__2__|__3__|__4__|__5__|__6__|__7__| incomprehensible
10. challenging |__1__|__2__|__3__|__4__|__5__|__6__|__7__| not challenging
11. pleasant |__1__|__2__|__3__|__4__|__5__|__6__|__7__| unpleasant

middle

12. interesting |__1__|__2__|__3__|__4__|__5__|__6__|__7__| dull
13. disgusting |__1__|__2__|__3__|__4__|__5__|__6__|__7__| attractive
14. comfortable |__1__|__2__|__3__|__4__|__5__|__6__|__7__| uncomfortable

15. worthwhile |__1__|__2__|__3__|__4__|__5__|__6__|__7__| useless

16. work |__1__|__2__|__3__|__4__|__5__|__6__|__7__| play

middle

17. chaotic |__1__|__2__|__3__|__4__|__5__|__6__|__7__| organized

18. safe |__1__|__2__|__3__|__4__|__5__|__6__|__7__| dangerous

19. tense |__1__|__2__|__3__|__4__|__5__|__6__|__7__| relaxed

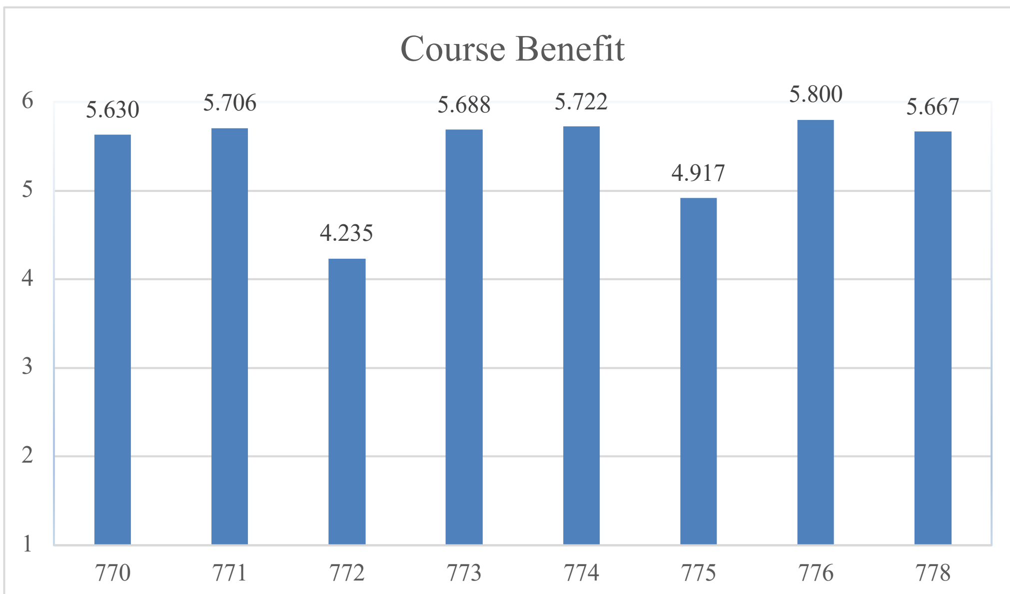
20. insecure |__1__|__2__|__3__|__4__|__5__|__6__|__7__| secure

APPENDIX S: POST-CAMPUS SUMMER SURVEY

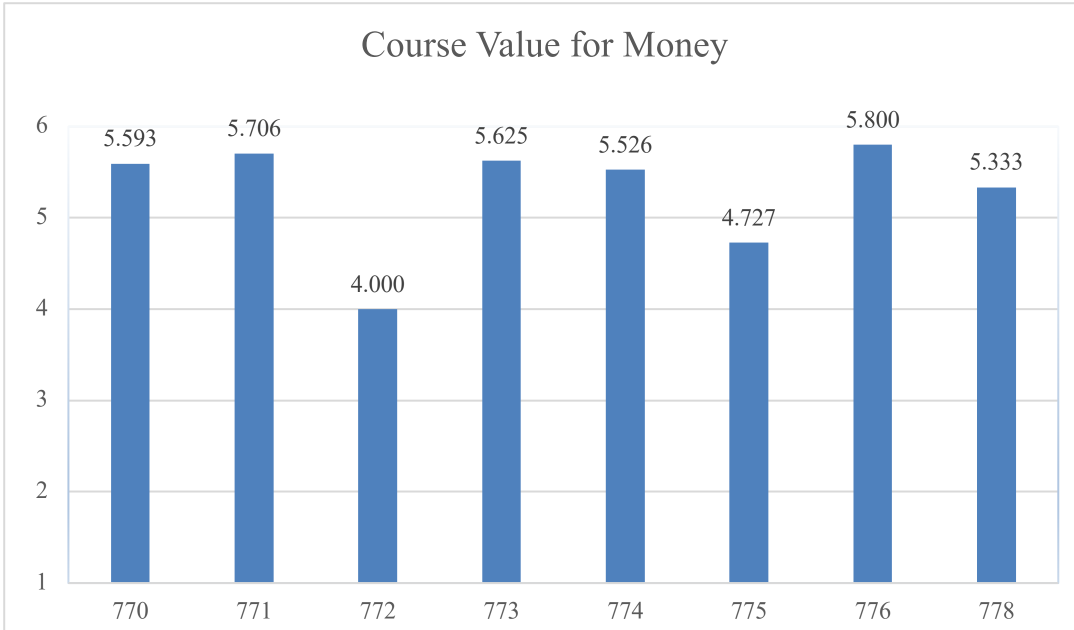
1. What was the most beneficial part of the two-week experience to you as a teacher? Explain why this was most beneficial.
2. What was the least beneficial part of the two-week experience to you as a teacher? Explain why this was least beneficial.
3. Before arriving on campus, if you had been asked to describe the research process, how would you have described it?
4. After this two-week experience, has your view of the research process changed? How did it change and why? If it did not change, why did it not change?
5. If you could change anything in the CHEM 776 class, what would you change and why?
6. What must not be changed in the CHEM 776 class? Why should this not be changed?
7. Will you change what you do in the laboratory work that you do with students because of something you experienced through this 776 class? If yes, what will you change and what caused this change? If no, why did these experiences not influence you to change?

APPENDIX T: COURSE FEEDBACK MEMBER CHECKING SURVEY

1. Please indicate which program courses you took from Fall 2021 to Spring 2023.
2. Question from survey: How would you rate the overall benefit of the course you took this semester? (Was taking the course beneficial?) [Likert Scale from 1 (not at all beneficial) to 6 (very beneficial)] Please share your thoughts on the average ratings of course benefit:



3. Question from survey: How would you rate the value for money of the course you took this semester? (Was taking the course "worth it"?) [Likert Scale from 1 (not at all worth the money) to 6 (very much worth the money)] Please share your thoughts on the average ratings of course value for money:



4. Please share any additional thoughts about your experience in MS program courses.

APPENDIX U: ALUMNI SURVEY

1. When were you a participant in this Master's program? (For example, Fall 2020 to Summer 2022)
2. How would you describe yourself as a teacher before the program?
3. How would you describe yourself as a teacher now?
4. What changes would you attribute to your experience in the program? Please explain any professional, pedagogical, or personal changes.
5. Looking back, how do you feel about your experience in the program? Please explain.
6. What changes would you make to improve the program, if any? Why?
7. Please share any other feedback regarding positive or negative aspects of your experience in the program.

APPENDIX V: GTA SURVEY

1. What was your experience like working with teachers from the Master's program?
2. Was it what you expected? Why or why not?
3. What do you think the teachers learned through this experience? What had you expected them to learn?
4. What did you learn through this experience? What had you expected to learn?
5. If you have worked with the teachers in the past, how did this summer differ from your past experiences? Please explain.
6. Would you like to work with the teachers again in the future? Why or why not?
7. What were your goals for this experience? Were these goals met?
8. Please share any other thoughts you have about your participation as a GTA with the M.S. teachers this summer.

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