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The Relationship Between Recollection, Knowledge Transfer, and Student Attitudes Towards Chemistry

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THE RELATIONSHIP BETWEEN RECOLLECTION, KNOWLEDGE TRANSFER AND STUDENT ATTITUDES TOWARDS CHEMISTRY

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

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To my heavenly Father without whom I could not be where I am today, I am very grateful.

"You are worthy of it all…

For from You are all things, and to You are all things,

You deserve the glory"

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ABSTRACT

THE RELATIONSHIP BETWEEN RECOLLECTION, KNOWLEDGE TRANSFER AND STUDENT ATTITUDES TOWARDS CHEMISTRY

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Certain foundational concepts, including acid-base theory, chemical bonding and intermolecular forces (IMFs), appear throughout the undergraduate chemistry curriculum. The level of understanding of these foundational concepts influences the ability of students to recognize the relationships between sub-disciplines in chemistry. The purpose of this study was to investigate the relationship between student attitudes towards chemistry and their abilities to recollect and transfer knowledge of IMFs, a foundational concept, to their daily lives as well as to other classes. Data were collected using surveys, interviews and classroom observations, and analyzed using qualitative methods. The data show that while most students were able to function at lower levels of thinking by providing a definition of IMFs, majority were unable to function at higher levels of thinking as evidenced by their inability to apply their knowledge of IMFs to their daily lives and other classes. The results of this study suggest a positive relationship between students' abilities to recollect knowledge and their abilities to transfer that knowledge. The results also suggest positive relationships between recollection abilities of students and their attitudes towards chemistry as well as their transfer abilities and attitudes towards chemistry. Recommendations from this study include modifications of pedagogical techniques in ways that facilitate higher-level thinking and emphasize how chemistry applies not only to daily life, but also to other courses.

CHAPTER 1: INTRODUCTION

A few years ago, I went to a non-academic conference and during the meet-and-greet session, I struck up a conversation with a girl from a different school. As we were talking, I asked what her major was and her response was a type of engineering that sounded complicated. I was impressed. She then asked me what my major was and I said it was chemistry. Her reaction to that statement was initially one of horror, as she stated that chemistry was extremely difficult and she hated the subject. As the horror wore off, she looked at me and said, "You must be very smart." Unfortunately, this is not a stand-alone experience. Over the years, I have had (and still have) very similar reactions when I state that I study chemistry. People seem to think chemistry is extremely difficult and only for very smart people, a sentiment I disagree with. I do know there are brilliant chemists, but I also believe chemistry is something that everyone should be able to relate to and not something to be feared. These experiences have propelled my interest in factors that influence attitudes towards chemistry.

As studies over the past 30 years have shown a decline in students' interest towards the sciences, studies that focus on students' attitudes toward science have been on the rise.[1] However, studies that focus specifically on undergraduate students' attitudes towards chemistry are not as common.[2-5] These attitudinal studies have investigated several factors that can influence student attitudes towards science. Research has been done on the relationship attitudes and factors like gender,[5, 6] conceptual knowledge,[7-9] achievement[5, 7, 10-11] and motivation/interest in the subject.[12-14]

Guiding Questions

Since research on the relationship between student attitudes towards science, and to some extent, chemistry specifically, and the factors mentioned above have been extensively researched, instead of looking at these factors, I would like to look at different factors that could potentially influence student attitudes towards chemistry.

For my master's thesis, I investigated the relationship between how students defined chemistry and their attitudes towards chemistry. This was an interesting question to study, however it was relatively difficult to answer because it is challenging to measure the "correctness" of the definition of chemistry. Because of this, I decided that for my dissertation, I would pursue something that I would be able to measure relatively easily (or so I thought) and so I decided to study knowledge transfer and how that relates to student attitudes towards chemistry.

After several attempts, conversations with my advisor, sweat and tears (on my part), I was finally able to come up with a concise research question stating what I wanted to investigate - "how do students' abilities to recollect information about intermolecular forces (IMFs) and transfer that knowledge of IMFs from class to class, as well as their everyday lives, influence their attitudes towards chemistry?" To investigate this question, I focused on the following guiding questions:

- What are students able to remember about IMFs?
- How are students able to transfer what they have learnt about IMFs to other classes and to their daily lives?
- How do additional courses influence this transfer of knowledge of IMFs to their daily lives?

- What is the relationship between recollection and transfer, and their attitudes towards chemistry?

As I began data collection, I thought it would be interesting to investigate transfer not only from the students' points of view, but also from the instructors' points of view. The final guiding question for this study was:

- What are some teaching strategies used by professors teaching freshman and sophomore level chemistry courses to facilitate transfer of knowledge between classes, as well as from class to students' daily lives?

CHAPTER 2: LITERATURE REVIEW

Attitudes towards Science

Definition of Attitudes

According to Klopfer,[15] "wide ranges of meaning are implied or intended when the affective terms, "attitude" and "interest" are used in educational circles." One of the challenges faced by researchers who have carried and continue to carry out attitudinal studies is the difficulty in providing a clear definition of what the word "attitude" means.[1, 4] According to Osborne et al.[1] attitudes are "feelings, beliefs, and values held about an object…," while Koballa defines it as "a predisposition to respond positively or negatively towards things, people, places, events, and ideas."[16] Similarly, Shaw and Wright define attitudes as "a set of affective reactions toward the attitude object, derived from the concepts or beliefs that the individual has concerning the object, and predisposing the individual to behave in a certain manner towards the attitude object."[17] Even though a clear-cut definition of the term attitude does not exist, Shaw and Wright postulate that all researchers would agree that the term attitude involves, "…an existing predisposition to respond to social objects which [in the presence of interaction with several variables], guides and directs the overt behavior of the individual."[17]

There are three main positions held by researchers on how to define attitude. The first position is that attitude is a multi-dimensional and complex construct that consists of affective, behavioral and cognitive components. The affective domain deals with how an individual feels about an object, the behavioral deals with the response an individual has towards that object, while the cognitive domain deals with how an individual thinks about that object.[18,19] This position suggests that all three constructs are separate aspects of attitude that influence attitude equally. The second position holds that attitude is a one-dimensional construct that is based solely on the affective domain. The third position, a middle ground between the first two, holds that attitude is indeed a complex construct, but that it consists of two components – affective and cognitive.[18] According to Bagozzi & Burnkrant, "…these components [affective and cognitive] simultaneously account for behavioral intentions. These intentions, in turn, lead to overt behaviors."[18]

I disagree with the second position that claims attitude is one-dimensional for a couple of reasons. Firstly, if indeed attitude is one-dimensional, then over the years, researchers would have come up with one overarching definition for attitude. Secondly, the affective domain itself is a complex construct that is made up of several other factors and influenced by others. The main difference between the first and third positions is the role behavior plays in determining attitude. I support the third position because I believe the behavior of the individual towards an object is due to the cognitive and affective components of attitude. In other words, the behavioral component does not directly influence the individual's attitude, but rather is a result of the individual's attitude. Brown et al.[20] used this two-fold model of attitude (affective and cognitive) to investigate undergraduate students' attitude towards studying chemistry. They used the Attitude to the Study of Chemistry Inventory (ASCI) scale[21,22] to measure undergraduate students' attitudes and found that the higher students scored on the affective and cognitive sub-scales contained in the ASCI, the more positive their overall attitude towards chemistry as measured by this scale.

In 2012, van Aalderen-Smeets et al.[23] proposed a model based on previous attitudinal work done by Eagly & Chaiken,[24] specifically for teachers' attitudes towards science that consisted of three different constructs: perceived control (self-efficacy), affective states, and cognitive beliefs. The perceived control (or self-efficacy) was the level of confidence the individual had in her ability to successfully handle a situation or deal with a task. The affective state or domain was the level of enjoyment or anxiety the individual felt about a certain concept, and cognitive belief was the perceived relevance of the individual towards the concept.[25] I would argue that the level of confidence proposed by van Aalderen-Smeets et al. could be categorized under the affective domain. According to Koballa, "the affective domain…includes a host of constructs such as attitudes, values, beliefs, opinions, interests, and motivation… [the affective domain] describes learning objectives that emphasize a feeling tone, an emotion, or a degree of acceptance or rejection…"[16] Confidence is essentially belief in one's ability to carry out certain tasks, and based on Koballa's definition, confidence can be considered a part of the affective domain. So in essence, both van Aalderen-Smeets et al.[23] and Bagozzi & Burnkrant[18] proposed models based on both the affective domain and the cognitive domain.

As I stated earlier, one of the challenges faced by researchers who carry out attitudinal studies is defining the term "attitude." In order to combat this challenge, I perused the literature to find how researchers have defined attitudes in the past so that I could use their work to inform the definition of "attitude" for this study. From previous definitions of attitudes[1,16-17] and the work done by researchers such as van Aalderen-Smeets et al. and Bagozzi & Burnkrant, for the purpose of this study, attitude will be defined as a set of affective and cognitive reactions towards a certain object that influences the way an individual responds (or behaves) towards that object. Providing this definition gives the readers a clear understanding of what is meant by “attitude” in this study, and will help with the design of the interview protocol for data collection.

Several instruments have been developed to assess student attitudes towards chemistry specifically, and science in general. These instruments include the Chemistry Attitudes and Experience Questionnaire (CAEQ),[26] the Chemistry Expectations Survey – CHEMX,[27] the ASCI and the modified version – ASCIv2,[28] and the Colorado Learning Attitudes about Science Survey (CLASS).[29] All these instruments have associated statistics showing them to be valid and reliable; however, they are all used primarily for quantitative studies. With Koballa’s definition of affective domain and my proposed definition of attitude in mind, I decided to use the models proposed by van Aalderen-Smeets et al. and Bagozzi & Burnkrant to design an instrument to qualitatively measure student attitudes towards chemistry. I believe this new instrument will paint a better picture of the participant’s true attitude towards chemistry as it is based on both the affective and cognitive aspects of attitude.

In their study, Bagozzi & Burnkrant found that the affective component of attitude influenced the individual’s behavior towards an object about three times more than the cognitive component.[18] Keeping this result in mind, for the purpose of this study, the affective and cognitive components of attitude were based on these four areas:

- Motivation of student to learn chemistry (affective domain)
- Self-reported attitude towards chemistry in general (affective domain)
- Self-reported attitude towards specific chemistry course (affective domain)
- Perceived relevance of chemistry (cognitive domain)

I decided on these four areas because I believe responses to these four constructs can accurately depict the individual's true attitude towards a specific object (chemistry), as they are parts (cognitive and affective) that influence the individual's attitude as a whole. A participant's self-reported attitude alone may or may not provide a true picture of their attitude towards an object because their response may be based on what they think the researcher desires to hear, regardless of their true feelings on the subject. This phenomenon called "response set" occurs when a participant responds to a question in a way they believe is desirable, and is common with questionnaires involving Likert scales.[30] Asking questions about the participant's perceived relevance of the object to them and motivation towards the object, combined with self-reported responses will help avoid response set, and give a clearer picture of the individual's true attitude towards the object. Figure 2.1 shows the instrument that will be used to measure student attitudes towards chemistry in this study.

- Attitude towards chemistry in general
    - I like chemistry – 1
    - I don't really care either way – 0.5
    - I don't like chemistry at all – 0
- Attitude towards specific class
    - I like my specific chemistry class – 1
    - I don't care either way about my specific chemistry class – 0.5
    - I don't like my specific chemistry class – 0
- Perceived relevance of chemistry
    - I think chemistry is relevant to my everyday life – 1
    - I think chemistry is only relevant to my career/my classes – 0.5
    - I don't think chemistry is relevant to me at all – 0
- Motivation to learn chemistry
    - I am motivated to learn chemistry – 1
    - I am motivated to learn chemistry ONLY so I can do well and pursue my future career – 0.5
    - I am really not motivated to learn chemistry – 0

Figure 2.1. Instrument used to rank students' attitudes towards chemistry.

During the interviews, students will be asked the following questions:

- How do you feel about chemistry in general?
- How do you feel about your specific chemistry class?
- Do you believe chemistry is relevant to your daily life? Why/Why not?
- Are you motivated to learn chemistry? Why/Why not?

The students will then be scored based on their responses (Figure 2.1) to the questions and their scores will determine their attitude towards chemistry. The scoring process is shown below:

Out of a possible four points:

- 3.5 - 4 points: positive attitude
- 2.5 – 3 points: slightly positive attitude
- 2 points: neutral attitude
- 1.5 points: slightly negative attitude
- 0-1 points: negative attitude

Based on this system and the working definition of attitude for this study, I will be able to use both the cognitive and affective domains to determine students' attitudes towards chemistry. The next sections will discuss the cognitive component of perceived relevance and the affective component of motivation and the rationale for utilizing these components in this study.

Student Perceptions of Relevance

Several quantitative studies have shown that students tend to have negative attitudes towards science courses, a trend that is even more pronounced as students continue in their formal education.[1-14,31-32] Studies have also highlighted that students tend to view these science classes as not relevant to their daily lives.[1,31,33-34] In a qualitative study carried out by Jelinek,[34] he found that there was a relationship between students' attitudes to learning science and their abilities to recognize connections between what they were learning and their everyday lives. These studies suggest a relationship between student attitudes towards their science courses and their perceived relevance of those courses to their daily lives.

According to Himschoot, perceived relevance is "a student's ability to see science in everyday context."[35] In other words, a student sees a concept as being relevant if he/she is able to take that concept and apply it outside the classroom. For a student to engage in meaningful learning of any concept and make connections to other areas, their perception of the relevance of that concept is important.[1,36] Specifically, in the sciences, for significant learning to occur, it is important for students to be able to make connections between other sciences and ultimately connect the knowledge to their individual world.[1,36-37] According to Van Aalsvoort[38] the relevance of chemical education can be defined in four ways – personal, social, professional, and personal/social relevance. Personal relevance deals with the ability of the student to relate information to their daily lives, while social relevance deals with the student's ability to relate information from their class to social issues. Professional relevance deals with the ability of students to relate information to their majors/future careers, while personal/social relevance ties both the individual relevance and relevance of social issues and builds responsible citizens.[35] For the purpose of this study, I decided to focus on the personal and professional relevance. I believe when students are able to find the relevance of knowledge to their daily lives and to their major/future career, they will then be more likely to find the relevance of that knowledge to social issues around them and ultimately become responsible citizens.

According to Danaia et al.,[33] students typically do not find science taught in class relevant to their daily lives or to their majors/future career. These researchers investigated Australian high school students, but this trend is true in other developed countries like the United States, the United Kingdom, and other countries in Europe.[5,31,39-41] Studies have shown that students with low levels of interest in a course typically do not see the relevance of the content taught to their lives (personal relevance).[36] Furthermore, students find it more difficult to find the relevance of physical sciences, compared to the biological sciences.[1,42]

Interestingly, studies have shown that younger students view science as very important and relevant to their lives compared to older students.[43-45] In their study, Agranovich and Assaraf[32] studied grade 4-6 students and found that the majority of students found the topics discussed in their science classes interesting. The researchers found that most of the students in the study were curious about the information they were learning, and as such, curiosity served as a driving force for what the students decided was relevant. They also found that the students' perceived level of the importance of the material also served as a driving force for their interest in the material, an idea agreed upon by other researchers.[1,46]

Hofstein & Mamlok-Naaman[13] suggest that if students are not interested in science, then it is harder for them to be motivated to learn and try to understand the concepts. They suggest that there could be a relationship between students' interest and attitudes towards chemistry and their perceived relevance of the content being taught, so if the student is able to relate to the content, that student will probably be more interested in the subject, which in turn influences their attitudes.

Miller et al.[9] carried out a study that sought to investigate student attitudes towards using instruments in a chemistry laboratory. Included in this work was identifying how students were able to relate chemical concepts to the instruments being used and how working in groups influenced students' attitudes towards the instrument as well as their conceptual understanding. This was a qualitative study and the participants were chemistry majors in a second semester general chemistry course, working in groups of three to four to separate and identify two organic compounds in an unknown solution using different instruments. The results of this study showed that the students' attitudes towards using instruments in lab were positive. The students thought the skills they learnt would be useful to them in the future, and also that using the instruments in the lab helped them connect chemistry concepts to the "real world." These results suggest that these students were able to begin to make the connection between "school chemistry" (what is taught in class) and "real chemistry" (what happens in the real world) and this connection could have influenced their attitudes towards using the instruments.

The data and results from the study carried out by Miller et al.[9] suggest a relationship between the students' attitudes towards their class and their abilities to make connections between what is taught in class and what goes on outside class. The students found human biology interesting because they could relate it to their own bodies – something they can relate to outside of class. However, one reason these students struggled with finding chemistry interesting was that they had difficulties understanding the relevance of the periodic table to their daily lives. Other studies have highlighted similar relationships between students' perceived relevance of the content taught in class and their attitudes and levels of motivation towards the class.[1,32,35,47] Findings indicate that students' attitudes towards science in general were positive, while their attitudes towards school science, specifically the physical sciences (e.g. chemistry and physics) were negative. The students believed that science was useful for jobs, even though it was not an easy discipline.

The concept of "school science" (what is taught in class) is of interest because studies have shown that students tend to have more positive attitudes towards "real science" (what actually happens in the real world), compared to "school science."[6,48] One reason for this could be because students generally view what they consider "real science" as something that is applicable to them on a personal level, while "school science" is something that is not relevant beyond the degree or certificate they are pursuing. Ebenezer and Zoller investigated students' perceptions and attitudes towards school science and found that the way science is taught in schools makes science appear boring to the students. They found that even though the majority of the student participants believed science was a valuable subject, very few of them wanted to further study science.[49] From the results of their study, the researchers concluded that "students wished to be taught [science] from their own perspectives…by relating school science to everyday science in the science classroom."[49]

Similarly, Habraken believes that the chemistry being taught in schools is "alienated" from what scientists actually do.[50] She believes that scientists see chemistry as interactions between different experiments and exploring ideas in order to develop hypotheses and theories. However, chemistry is taught to students in ways that do not help them see the true interactional nature of chemistry, of science as a whole. According to Tytler and Osborne,[51] there is a difference between attitudes of students towards "*doing* school science" and "science in general" (i.e. real science). They believe that these attitudes towards school science may play a significant role in students' decisions to continue studying science beyond what is compulsory.

In a study by Habraken et al.,[52] 29 high school seniors worked with molecular models to enable them to explore the nature of chemistry research. These students were divided into three groups and each group had the opportunity to visit and spend some time in a chemistry research lab. After being in the lab, the students were asked to write essays on "School Chemistry vs. Chemistry in Research." The results from this study showed that the students believed chemistry carried out in the world ("real chemistry") was different from what they learnt in class ("school chemistry"). This study did not specifically investigate the relationship between the students' attitudes and real versus school chemistry, however students had comments like, "Never thought the things we learn are actually used in real life…" and "Chemistry then is not just calculating stupid acid-base reactions and equilibria and number-juggling…" These comments suggest that students may have a more favorable response to "real chemistry" compared to "school chemistry." This finding is in line with what Bennett and Hogarth[6] suggest in their study regarding "school science" and "real science." They found that interest in physical sciences for 280 English and Welsh students in their first, third and final year of high school decreased as the students got older. They also found that the students generally had a more positive attitude towards what they considered ‘real science,’ which is actually done in the real world, compared to the science they study in school.

The studies mentioned above have shown that students’ perceptions of the relevance of what they learn are related to their attitudes towards the subject, as well as their motivation to learn the subject. Literature has shown that students are more motivated to learn concepts they find more relevant to their daily lives and their society, compared to abstract concepts.[32,34,53] In fact, according to Wolter et al., “when students become curious about a topic, they view it as more relevant to their lives and become more motivated to learn.”[54] This relationship among attitude, relevance and motivation is one of the reasons I decide to investigate relevance and motivation as constructs that influence a student’s overall attitude towards an object. By investigating students’ perceptions of relevance as a part of their attitude towards chemistry, this study will add to the body of knowledge on the relationship between perceived relevance and attitude. Furthermore, because I am also interested in the students’ abilities to transfer knowledge to both other classes and to their daily lives, this study will go a step further and shed light on the relationship between participants’ perceptions of the relevance of the information they have learnt and their abilities to transfer knowledge.

Motivation

Motivation is a concept in psychology that has been studied over the years by several researchers. This section cannot (and does not seek to) cover all the details, but I will attempt to give a brief history and provide a rationale for why motivation was considered a part of attitudes for this study. For a more thorough look into the history and theories of motivation, work by researchers like Graham & Weiner[55] and Gollwitzer & Oettingen[56] are good starting points.

Background

The concept of motivation can be traced back to the age of the ancient Greeks.[57] Several theories of motivation exist, and as with other constructs discussed in this review, there is no firm consensus among researchers concerning what motivation is; there are differing perspectives among researchers because motivation is such a broad and complex concept.[58-59] Some researchers believe motivation is one of several variables that influence behavior.[56,60-61] According to Repovich, motivation is "an important determinant in why a person may pursue a particular activity."[61] Others believe it is an actual behavior.[57,59] According to Bernard et al., motivation is "a purposeful behavior that is ultimately directed towards the fundamental goal of inclusive fitness."[59]

There are several theories regarding motivation, including behavioral, cognitive, humanistic, social and spiritual theories, but for the purpose of this study, I will focus on the humanistic theories because these theories are centered on the idea that humans are responsible for their actions and have the choice to change their behavior.[58] If I did not believe in the idea that humans are able to change their actions towards certain objects, then this study would be pointless, because regardless of what I find, if humans are unable to change, there is no point in investigating factors that influence their attitudes and how these factors influence these attitudes.

Several humanistic theories exist, but I will discuss the two that I believe are most relevant to this study– Maslow's theory of the hierarchy of human needs and the Self-Determination Theory (SDT), established by Deci and Ryan.[58] Maslow, who is considered by some as the father of humanistic psychology[62] established that there are five basic needs of individuals: physiological needs, safety needs, belongingness and love needs, esteem needs, and the need for self-actualization.[63] For this study, the type motivation being investigated (motivation to learn chemistry) would fall under the esteem needs and/or the need for self-actualization. According to Maslow, esteem needs have two classifications: a) the desire to achieve mastery and competence in whatever field the individual chooses to pursue, and b) the desire to establish a reputation that is respectable in the sight of other individuals. The need for self-actualization is a step above the esteem needs in that with self-actualization, there is a passionate desire, or drive in an individual to do what she believes she was born to do.[63] A student's motivation to learn chemistry is very likely going to fall under these two categories of needs. Many students will either be driven to learn so they can do well and be respectable in their chosen field of study, or because they believe there is an innate drive in them to study chemistry.

This idea of esteem and self-actualization needs by Maslow ties in to Ryan & Deci's Self-Determination Theory (SDT).[64-65] The SDT also postulates that humans are responsible for their motivation. However, this theory goes further to suggest that there are different types of motivation and that the environment and conditions the individual is exposed to can foster growth tendencies in that individual's level of motivation.[64-65] Ryan & Deci believe motivation can vary in both the level of motivation and the type of motivation. Based on the SDT, they believe there are two basic types of motivation: intrinsic motivation and extrinsic motivation.[66] The concept of extrinsic motivation is defined as doing something because it leads to a separate, ultimate outcome.[64, 67] This definition has been around for a while, as behavioral psychologists believe every behavior carried out by an individual is to achieve a certain goal and not just for the pleasure of the activity. Behavioral psychologists like Watson, Hull and Skinner have work that supports the idea of extrinsic motivation.[68-71] Skinner's work revolved around operant conditioning, which postulates that a behavior is controlled by the consequences attached to that behavior. Similar to work carried out by Pavlov, where dogs were conditioned to respond to a certain stimulus, Skinner also carried out work on pigeons showing the consequences (reward or punishment) associated with a behavior was responsible for shaping that behavior.[70] Watson carried out the controversial rat experiment involving a 9-month old boy, where he and his partner successfully conditioned the little boy to be scared of a white rat by clanging an iron rod whenever the rat was presented to the boy.[71] These researchers all share the same idea that behaviors are based on external stimuli – extrinsic motivation.

Intrinsic motivation is defined as an internal drive to do something because the individual finds it either interesting or enjoyable.[61,66] In his article, White discussed exploration as a drive for certain behaviors in animals.[72] He found that several organisms participated in different types of exploratory, curiosity-driven behaviors, without reward or reinforcement of their behaviors. For example, a study found that when rats were put in an unfamiliar place with several new objects in the space, they excitedly explored the area. Once the novelty wore off, the rats stopped exploring, however, once newer objects were introduced, they started exploring again.[72] According to Amabile,

> Individuals are intrinsically motivated when they seek enjoyment, interest, satisfaction of curiosity, self-expression, or personal challenge in the work…

> [and] are extrinsically motivated when they engage in the work in order to obtain some goal that is apart from the work itself.[73]

Repovich states that intrinsically driven students are “task-oriented” meaning that these students are driven to master what they are motivated to do. Conversely, extrinsically driven students are “ego-oriented” and are “primarily interested in their class standing and care little how they achieve the grade.”[61]

Reiss[46] argues that humans are too diverse to be categorized as solely being either intrinsically motivated or extrinsically motivated. He believes that “all human motivation arises from an intrinsic source” and that extrinsic motivation ultimately arises from an internal drive to achieve a certain goal.[46] Similarly, Ryan and Deci,[64] believe motivation is a multidimensional phenomenon, as people can have different amounts (levels) of motivation as well as different types (orientations), but they also believe that there can be different types of intrinsic and extrinsic motivations. For example,

> “…a student can be highly motivated to do homework out of curiosity and interest, or alternatively, because he or she wasn’t to procure the approval of a teacher or parent. A student could be motivated to learn a new set of skills because he or she understands their potential utility or value or because learning the skills will yield a good grade and the privileges a good grade affords. In these examples the amount of motivation does not necessarily vary, but the nature and focus of the motivation being evidenced certainly does.”[64]

Ryan and Deci[64] argue that based on different individual reasons and goals, there are different types of motivation, and I agree with this idea. I also agree with Reiss that humans are too complex to be defined solely by intrinsic and extrinsic motivations.

Motivation, Attitude and Student Learning

Several studies have investigated student attitudes and levels of motivation to learning and have found a positive relationship between these two constructs; that is, a positive attitude correlates with increased motivation to learn, and vice versa.[1,74-76] Studies investigating the role(s) motivation plays in education have been on the rise in recent years[77] as researchers are beginning to realize the importance of motivation to student learning. Vedder-Weiss and Fortus[74] studied Israeli-Jewish students in grades 5-8 from two different types of schools: democratic and traditional. They investigated whether the decline in students' motivation to learn science was inevitable during these school years and found that in the democratic schools, where the class sizes were smaller and the students more engaged due to the teaching method, the level of motivation stayed constant. However, at the higher grades of the traditional schools, the students began to develop resentment towards science-related activities, which in turn influenced their performance. The researchers did not state whether they investigated intrinsic or extrinsic motivation, but the results from this study suggests that the student's level of motivation can be influenced by a variety of factors, including the learning environment.

Other studies have found that teaching styles and the level of engagement in the learning environment can play a role in motivating students to learn and their attitudes towards science.[25,32,39,78-81] Riegle-Crumb et al.[25] investigated how inquiry-based science courses influenced the attitudes of pre-service teachers towards science and found that after taking the inquiry-based course, the pre-service teachers had more positive attitudes towards science. The post-test analyses showed that these pre-service teachers enjoyed science more, had less anxiety towards science, and viewed science as more relevant to them. Osborne and Collins[39] carried out a qualitative study investigating the experiences and beliefs of student about science and found that the students believed the teachers played an important role in motivating students to learn. The researchers found that students had high levels of engagement in a class where the teacher "made lessons 'fun', either through their methods of presentation of the material, or through the organization of work…" Cetin-Dindar[80] and Thompson & Windschitl[81] found that the level of engagement of the student in the science class influences their perception of the relevance of the course to them on a personal level, and their motivation to want to learn.

Motivation has also been linked to performance (grades/achievement). Lynch and Trujillo[82] studied the motivational beliefs and learning strategies of 66 college students in the second semester of organic chemistry. They found that intrinsic goal orientation was positively correlated with academic performance, while extrinsic goal orientation was negatively correlated to academic performance. Jurisevic et al.[83] also investigated the relationship between 295 Polish and Slovenian high school students' motivational orientation and their achievements in chemistry. They found that the quality of the students' motivation was positively correlated to their performance, specifically grades from their previous chemistry class. Their results also suggest that the types of activities that go on in the classroom may influence the level of students' motivation.

So, how do the different ideas these different motivation researchers like Maslow, Ryan & Deci, and Reiss tie into this study? As part of determining student attitudes towards chemistry, I chose to investigate motivation as a variable that influences attitudes because I believe motivation, like attitude and perceived relevance, is a variable that can influence an individual's behavior towards a certain object. As a variable that influences behavior, I believe motivation is one that can be developed and enhanced by the efforts invested by both the teacher and the student. A main reason I chose motivation as a variable that helps define attitudes is that it is a dynamic construct – I believe they can be influenced by teaching styles and the learning environment, which are variables that instructors can control. Maslow[63] and Ryan & Deci[64-65] in their motivation theories state that the individual is in charge of their actions/behaviors, and Ryan & Deci go further to state that motivation, which results in these actions/behaviors, can be influenced by the individual's environment.[64-65] Using these theories as a basis, I identified what motivates students to learn (or not learn) chemistry, determined their attitudes towards chemistry, and suggested steps educators can capitalize on to motivate students, and improve their attitudes towards chemistry.

Why are attitudinal studies important?

Studies have shown that negative attitudes of students have towards science are a problem.[1-14,31] In 1994, Simpson et al.[84] stated that many reports exist in the science education literature that have sought to design methods to improve student attitudes towards science, and today, over 20 years later, that number continues to grow as researchers are still seeking ways to improve student attitudes towards science. Osborne et al. state "…our understanding of the nature of the problem [students' increasingly negative attitudes towards chemistry] has possibly improved, although possibly not our understanding of its remediation."[1] Researchers agree that the negative attitudes of students toward science are a problem that exists,[1-14,31] however, we are still investigating ways that these attitudes can be improved.

Several studies have investigated and are still investigating student attitudes towards science. Osborne et al.[1] proposed that attitudes towards science have been a concern in the science education community because of the decline of students' level of interests towards the field. In a study carried out by Sjoberg and Schreiner,[31] the researchers found that students from certain developed countries scored high on the Trends in International Mathematics and Science Study (TIMSS) and the Programme for International Student Assessment (PISA). However, these same students trended towards lower scores on surveys of interest for science and attitudes towards science. This study was carried out internationally and the researchers found that while a majority of the participants had positive attitudes toward science and technology, in more developed countries, students had less interest towards science and technology.

Simpson et al.[84] state that attitudinal studies are important because a change in attitudes could lead to a change in behavior of students towards science. In addition, Fulmer[8] suggests that improving students' attitudes towards science can contribute to making the society more scientifically literate. Venville et al.[12] also believe that developing a scientifically literate society is important so that individuals are able to understand the science associated with their daily lives, enabling them to make educated decisions about both local and global issues. Research has shown that there is a relationship between the economic performance of a country and the number of engineers and scientists the society produces.[1,85] This suggests that the more scientifically literate a society, the more improved their economic performance.

Additionally, student attitudes have been linked to retention rates.[8,12,51] The more positive student attitudes are towards a subject, the higher the chances of the student being retained in that specific discipline. From a practical standpoint, a higher retention rate in a field, chemistry for instance, implies that there are more students electing to major in chemistry, which means more revenue for the department. Attitudinal studies in the science field are important not only for the economic growth of the various science departments, but also for the economic growth of the society as a whole. This study is important, as it will increase knowledge through research on student attitudes towards science, specifically focusing on chemistry and undergraduate student. Furthermore, it will highlight the influences of constructs like motivation and perceived relevance on student attitudes towards chemistry.

Prior Knowledge/Recollection

For the purpose of this study, prior knowledge and recollection will be regarded as the same concept. Prior knowledge is a widely studied concept, and as such has a variety of definitions.[86-87] A definition of prior knowledge provided by Hailikari et al. is "a multidimensional and hierarchical entity that is dynamic in nature and consists of different types of knowledge and skills."[88] According to Jonassen & Grabowski,[89] prior knowledge is "knowledge, skills or ability that students bring to the learning process." Dochy argued that this definition proposed by Jonassen & Grabowski was too vague and provided a more specific definition:

> "the whole of a person's actual knowledge that a) is available before a certain learning task, b) is structured in schemata, c) is declarative and procedural, d) is partly explicit and partly tacit, [and] e) is dynamic in nature and stored in the knowledge base."[86]

This variety of definitions indicates there is no standard definition of prior knowledge, and speaks to the "dynamic"[86,88] nature of prior knowledge, and knowledge in general. A common theme in all three definitions is that prior knowledge is an ability, which an individual has that can help the individual gather more knowledge.

According to Dochy,[86] there are two types of prior knowledge – declarative knowledge and procedural knowledge. Declarative knowledge is the "knowledge of facts and meanings that a student is able to remember or reproduce,"[88] while procedural knowledge "is characterized by an ability to integrate knowledge and understand relations between concepts and, at the highest level, apply this knowledge to problem-solving."[88] Anderson[90] defines declarative knowledge as "knowing that" and procedural knowledge as "knowing how." This study will investigate both the declarative and procedural knowledge because I am interested in what information the participants are able to recall about the concept of IMFs, as well as how they are able to integrate that knowledge into other areas, that is, their abilities to transfer knowledge.

Researchers have recognized prior knowledge as a very important factor in the learning process.[88,91-95] Hailikari et al.[88] assessed how prior knowledge influences learning in a pharmaceutical chemistry course by investigating predominantly first-year undergraduate Finnish students. They found that performance on most of the prior-knowledge tasks assigned at the beginning of the course correlated with the final grade in the course. Thompson and Zamboanga[95] also investigated the effect of prior knowledge on students' performance in a course. A pre-test was administered to undergraduate students in a psychology class and these same questions from the pre-test were included throughout the semester on class exams. They found that even though a majority of the students performed poorly on the pre-test, the pre-test scores were positively correlated with performance on exams and ultimately the final grade in the course.

Correct prior knowledge can facilitate learning, and some researchers argue that incorrect or partially correct prior knowledge may be detrimental to the learning process.[94,96-98] Cordova et al.[99] suggest that the conflict between prior knowledge and the new information can pose a problem to the learning process. This conflict can hinder correct understanding of the new information because of the students' belief in the incorrect information.[95,100] According to Hailikari et al. "if students possess inaccurate prior knowledge and misconceptions within a specific domain it can make it difficult to understand or learn new information."[100]

On the other hand, Dochy et al.[93] suggest that students with some form of prior knowledge, even if it is inaccurate, have an edge over students with no prior knowledge at all. They argue that the students with incomplete/incorrect prior knowledge at least have a knowledge framework from which to work. Byrnes & Guthrie[101] found that students who had some level of prior knowledge were able to search a textbook for answers compared to students with no prior knowledge, while Etta-AkinAina[102] found that students with prior knowledge were able to take better notes compared to students with no prior knowledge.

As discussed above, studies have shown that prior knowledge is an important aspect of the learning process, an idea that is logical. From a constructivist's point of view, individuals construct knowledge based on personal experiences, including prior knowledge. For an individual to keep constructing knowledge they need an existing framework of prior experiences (and knowledge). The quality of construction of knowledge, and ultimately learning, will be influenced by the quality of the prior knowledge of the individual. As such, one of the objectives of this study is to determine the level of prior knowledge the participants are able to bring into a new course by asking the participants questions regarding how much information they remember about the concept of IMFs, and investigate the relationship between this prior knowledge, students' abilities to transfer knowledge, and their attitudes towards chemistry.

Knowledge Transfer

What is Transfer?

Transfer is also another widely studied concept that researchers have been investigating for over a century.[103] One of the earliest recorded studies of transfer was carried out in 1901 by Thorndike and Woodworth.[103] They investigated the effects of training on students' abilities to estimate the areas of geometric shapes of increasing size. They believed that if transfer truly occurred, students should become increasingly more adept at judging the areas of the bigger shapes. However, their study showed no improvement in the students' abilities to judge the area of the shapes even as they increased in size. Thorndike and Woodworth's classic study suggests the occurrence of transfer is not typical, and in the unlikely scenario where transfer does occur, it occurs between similar domains. Other researchers have made statements similar to Thorndike and Woodworth. Bassok and Holyoak[104] found that physics students were unable to transfer knowledge learnt in their physics class to similar algebra problems. According to Detterman, one of the more pessimistic researchers who have argued against transfer, "…there is very little empirical evidence showing meaningful transfer to occur and much less evidence showing it under experimental control."[105] It is not difficult to find studies that have argued against transfer, and according to Barnett and Ceci, "there is little agreement in the scholarly community about the nature of transfer, the extent to which it occurs, and the nature of its underlying mechanism."[106]

While some researchers have argued against transfer, others have argued for transfer. One of the first researchers to argue for transfer was Judd,[107] who suggested that if the teacher highlighted transfer during instruction and the students understood that the importance of the transfer, then transfer would occur. Gick and Holyoak found that there was a relationship between the training the students received and the transfer task if there were similarities between the two (i.e. similar domains).[108] Other researchers have obtained similar results suggesting the existence of transfer.[109-110]

According to Detterman, transfer has been extensively studied in psychology, and "nearly everyone has something to say about transfer."[105] Detterman defines transfer in behavioral terms as "the degree to which a behavior will be repeated in a new situation."[105] Also from a behavioral standpoint, Phye and Sanders broadly define transfer as "…an interaction of prior knowledge and the conditions under which new knowledge is acquired."[111] Several other researchers have defined transfer as the ability of an individual to take knowledge from a previous context and apply it to a new context.[112-115] However, even with the popularity of transfer studies, there is still not one agreed-upon definition of the term, and researchers are still debating whether transfer actually occurs.[106] For the purpose of this study, knowledge transfer will be defined as the ability of an individual to take a concept learnt in a previous setting and apply that knowledge to a new setting.

Pugente and Badger[109] suggest that for students to develop a deeper understanding of concepts, they need to develop their own mental framework that contains a basic knowledge and understanding of concepts, but also have the ability to apply that knowledge to something else (transfer of knowledge). These researchers believe that a "higher-level cognitive process" is required for students to develop their mental framework.[109] These researchers attempted to incorporate higher levels of Bloom's taxonomy, like "application" and "synthesis" into their classrooms as opposed to staying at the basic levels. Pugente and Badger suggest that if students are able to make connections between the principles they learn in general chemistry and the reaction mechanisms in organic chemistry, this will enable them to understand what is going on in the classroom. A student that has an understanding of what is going on is more likely to be interested in the subject as well as have a positive attitude towards the subject compared to a student who is totally lost in the class.

Pugente and Badger[109] found that once the students were able to make these connections between what they learnt in general chemistry and the mechanisms for organic chemistry reactions, their learning improved. The researchers are not clear about what they mean by improved learning, and they do not discuss how this was measured. However, they have suggested that a relationship exists between the ability to transfer knowledge from what has been learnt before (prior knowledge) and an improved understanding of concepts.

Types of Transfer

Just as there are several definitions of transfer, there are also several criteria for distinguishing between different types of transfer. Some types of transfer include:

- Positive and negative transfer
- Near and far transfer, and

- Specific and non-specific (general) transfer.

Positive transfer occurs when the knowledge learnt in one situation improves the individual's performance in another situation, while negative transfer occurs when the individual's performance in a different situation is adversely impacted.[114] An example of positive transfer could be a student-athlete taking the discipline her training as an athlete instilled in her and using that in her classes to improve her study habits. Conversely, a personal example of negative transfer would be trying to learn to hit a two-handed backhand in tennis after playing with a one-handed backhand for a while. My knowledge of the one-handed backhand adversely affected my ability to correctly hit the two-handed backhand because my arm had been conditioned to hit the ball in a certain way (one-handed) that did not line up with the new way (two-handed), making my body (and mind) resistant to change.

Near transfer is "the use of knowledge in a situation that is similar to the original learning situation."[116] On the other hand, far transfer is the use of knowledge in a situation that is different from the original learning situation.[105,116] An example of near transfer could be a student taking an exam where the questions are similar to questions encountered on a homework assignment, practice problems or even class (original learning situation). An example of far transfer could be a student taking what they learnt in an algebra class and applying it to a physics class. The problem with near and far transfer is its subjectivity, as what some researchers may define as near transfer may be categorized as far transfer by some other researchers.[116-117]

Transfer can also be categorized based on the specific content being transferred. Specific transfer involves applying the knowledge learnt from one situation to another, while general (non-specific) transfer occurs when skills that are independent of the content taught are transferred. A pharmacy student who applies knowledge of IMFs learnt in a general chemistry course to how certain drugs work in a pharmacology course is exhibiting specific transfer. Conversely, a student who learnt to delegate tasks in a chemistry laboratory course and used that skill to help her in a group work project in her psychology class is exhibiting general transfer.[105,116]

Even though researchers disagree on whether transfer occurs and how much transfer occurs, the extensive effort towards studying transfer shows that transfer is an important piece of the learning process. According to Bassok, "most educators hope to impart knowledge that can be applied to situations other than those that were directly taught."[118] As educators, we would be doing our students a disservice if the knowledge and skills being taught could not be applied to other situations. Learning is enhanced when individuals are able to take the knowledge and skills they learn and apply it to other areas.[115] As Perkins and Salomon suggest, "…the ends of education are not achieved unless transfer occurs."[114]

Transfer is not a straightforward construct to deal with, as evidenced by the lack of agreement by researchers who have been investigating it for over a century, and this study does not seek to redefine transfer or establish different categorizations of transfer. This study does seek to investigate what specific knowledge of IMFs students are able to transfer (or not) from a chemistry class to other classes (near transfer), and to their daily lives (far transfer) and potentially highlight some factors that may affect this transfer (or lack of transfer) – factors that can be further investigated.

Relevance of This Study

According to Mestre, "some initial acquisition of knowledge is necessary for transfer, and the more knowledge and mastery one has in a domain, the better the ability to transfer knowledge."[119] In order to talk about knowledge transfer, there needs to be prior knowledge. It is not possible to transfer knowledge that has not been gained previously. According to Brooks and Dansereau,[120] prior knowledge can influence subsequent learning (which the researchers used interchangeably with transfer) by providing a framework for the new knowledge, by elaborating on the framework for the new information, and by providing analogies that can assist in obtaining the new information. In other words, prior knowledge can serve as a backbone for subsequent knowledge gained, and ultimately knowledge transfer.

In their study, Hailikari and Nevgi[121] investigated the relationship between prior knowledge and students' success in chemistry. The participants were enrolled in the first semester sequence of organic chemistry for chemistry majors and minors. Questionnaires were used to assess the students' prior knowledge and performance on the final exam was used to measure student achievement. Their results revealed that not only was there significant variation in the performance of the students on the prior knowledge questionnaire, but students who majored in chemistry did much better on the prior knowledge questionnaire compared to students with other majors. This study did not investigate the reasons behind this occurrence, why did chemistry majors retain more than non-chemistry majors? However, the results did show that there is a moderate correlation between prior knowledge and student achievement in chemistry. If a student could retain knowledge from previous classes and transfer that knowledge to new tasks and settings, the level of understanding of that student would probably be higher than a student who does not retain anything from previous classes. The student who has a higher level of understanding is more likely to have a more favorable attitude and a higher level of achievement compared to a student who is unable to retain much. According to Lewis and Lewis,[122] students are prevented from contributing to other science fields when they do not have a basic understanding of chemistry. They believe that prior knowledge plays a role in how successful students are in chemistry courses.

This qualitative study seeks to investigate the relationship among attitude, recollection and knowledge transfer. The decline in positive attitudes of students towards science in general, but more specifically physical sciences (including chemistry and physics) remains a major concern for science education researchers today, as they continue to investigate ways to improve student attitudes towards chemistry. Studies have investigated relationships between student attitudes towards science and several constructs, including conceptual knowledge,[9,13] achievement,[7,10-12,123] and interest levels,[10,12] while other studies have investigated relationships between transfer, prior knowledge and achievement.[121-122] However, based on my literature search, I have not yet found a study investigating the relationships between student attitudes towards chemistry, their abilities to recall information, and their abilities to transfer the information recalled. This study is novel in that regard, and will provide information that can be built upon for future studies to help elucidate the problem of the declining positive attitudes of students towards science in general, and chemistry specifically.

Research has shown that many students are unable to attain an acceptable level of transfer,[114] and this study may begin to answer the question ‘why?’ According to Mestre, even though our knowledge about transfer keeps increasing “we know little about how to construct classroom environments for learning at levels that foster transfer.”[113] Understanding what information students are bringing in from previous classes and the relationships between their abilities to transfer that information to new areas and their attitudes towards chemistry, could potentially shed light on how the current chemistry curriculum is serving our students, and provide innovative ideas on how to improve the curriculum. Investigating the knowledge students are able to transfer will shed light on what students know about chemistry, whether this knowledge is accurate or not. Additionally, asking questions about the beliefs of educators about transfer and techniques they use to facilitate transfer in their classroom could potentially add to the understanding of what classroom environments currently look like and how they foster (or do not foster) transfer.

CHAPTER 3: METHODOLOGY

Motivation for study

Mertens defines research as “one of many different ways of knowing or understanding.”[124] A researcher asks questions that ultimately lead to other questions and hopefully some answers along the way. I have found that the beauty of research is that it opens the researcher’s mind to thoughts and ideas that were not originally anticipated. Chemistry has always been fascinating to me, from the titrations using indicators like phenolphthalein, to the stoichiometric calculations and even my struggles with organic chemistry. Chemistry is all around us; in fact, everything we encounter involves chemistry and so it disheartens me when I hear of the negative experiences and stereotypes people have about chemistry. I initially wanted to pursue research in analytical chemistry, but after overhearing a conversation where a few students were lamenting about their “lives being over” because of the chemistry course they had to take that semester, I became curious as to why this was their attitude towards the chemistry course they were about to take.

I believe that attitudes towards chemistry are important because they influence a student’s decision to pursue a certain field of study. I also believe attitudes are important because they influence perceptions. An individual with a negative attitude towards chemistry is more likely to perceive chemistry as a field that is neither useful nor relevant, compared to an individual with a positive attitude. I do not believe it is possible, or even realistic, for every individual who takes a chemistry course to fall in love with chemistry, but I do believe it is possible for every individual to leave a chemistry class with an accurate appreciation of chemistry. I believe the key to making this happen is understanding the different factors that influence student attitudes towards chemistry. There are several factors that can influence students' attitudes towards chemistry and for this study I decided to investigate how a student's ability to recollect knowledge and transfer that knowledge from class to class, and also from class to daily life, influences his/her attitude towards chemistry.

Types of Educational Research Methods

There are three types of research methods in the educational research field: quantitative methods, qualitative methods and mixed methods. All three methods have their strengths and weaknesses and should be utilized based on the types of questions the researcher attempts to answer. Tolmie et al. describe quantitative research methods as methods that are involved in "describing 'reality' through numbers, in order to build models of different kinds."[125] Quantitative research allows the researcher to obtain responses to a limited number of questions from a large number of individuals.[126] For this type of research, surveys and questionnaires are the typical instruments used to collect data. The results generated from quantitative research methods are statistically analyzed and typically generalized to large populations. Depending on the research question, generalized results can be very important, but for the purpose of this study, I am not trying to make statements that can be applied to large populations. One of the main disadvantages of quantitative methods is that it does not answer the question "why?" A quantitative study provides information about general trends for a particular situation and population, but it will not tell us why those trends are observed for that specific population.

Qualitative research methods on the other hand describe and help the researcher understand the experiences of individuals relative to certain situations and/or ideas, as well as these individuals' responses to these ideas and/or situations.[124,126-127] In order to draw out these types of information from the individuals, qualitative researchers typically use open-ended interview questions, observations, field notes and focus groups. [124, 127] Qualitative research data are rich in description; however, unlike quantitative studies, they usually cannot be applied to large populations. One of the main disadvantages of qualitative research is that the sample size is very small, compared to that used in quantitative research. Qualitative research answers the questions, "why?" and "how?" However, because of the small sample size, the answers to the questions posed pertain to the specific population under investigation, and these answers can only be loosely applied to different populations. For the results to be generalizable to other populations, more studies would need to be carried out using more populations that are diverse.

A mixed-methods study uses both quantitative and qualitative methods to answer research questions. Using mixed-methods to answer a research question combines the strengths of both qualitative and quantitative research methods, but the disadvantage to this approach is methodological complexity, which can in turn pose a threat to the reliability and validity of the study. According to Terrell,[128] a mixed-methods study should be utilized in a situation where using only one of the two types of research methods (qualitative and quantitative) is not sufficient to address the research question, or where using both methods gives a better understanding of the research question. There are three main types of mixed-methods designs: a design that is quantitative dominant (sequential explanatory design), a design that is qualitative dominant (sequential exploratory design), and a design where both methods carry equal weight (concurrent triangulation strategy).[128]

Sequential Explanatory Design

Sequential explanatory design methods are used to explain trends observed from a quantitative data set. Using this design, quantitative data are first collected and analyzed. The results of the quantitative study inform the collection of the qualitative data. One of the strengths of this design is that compared to other mixed methodologies, it is not complicated to implement the two-stage data collection process. In addition to the ease of data collection, inconsistencies in the results obtained from the two data sets is not a problem, as the qualitative data attempt to explain the trends observed from the quantitative data, as opposed to trying to reinforce the results obtained from the quantitative data. A disadvantage to this type of design is the length of time it takes to implement both phases of the data collection. The quantitative data must first be collected and analyzed before the qualitative part of the study can be fully designed. Furthermore, because the second phase of the data collection hinges on the results obtained from the first phase, gaining approval from the Institutional Review Board (IRB) can be cumbersome because of the lack of specificity about the second phase of the study. [128]

Sequential Exploratory Design

The sequential exploratory design is very similar to the explanatory design; however, the difference here is that the qualitative data are collected and analyzed first and then the quantitative data are collected. This type of design is utilized to explore different variables and ideas and then assess whether or not the themes observed in the qualitative study can be generalized to a larger population. One of the advantages of this design, like the explanatory design, is that implementation is straightforward due to the two-stage data collection process. Another strength of this design is that the quantitative aspect of the design makes it more attractive to researchers who are skeptical of the qualitative approach. As with the explanatory design, the time it takes to implement both phases of the study as well as complications with obtaining IRB approval are both downfalls of this type of mixed-methods design. Additionally, distilling the results from the qualitative portion to be used in collecting the quantitative data can be challenging and time consuming.[128]

Concurrent Triangulation Strategy

Using the concurrent triangulation strategy, both quantitative and qualitative data are collected simultaneously but analyzed separately. After the data sets have been individually analyzed, the results from the two sources are combined in an attempt to answer the same research question. This design is typically used to validate results from different sources, which is one of the advantages of using this design. Another advantage is that compared to the sequential designs, the concurrent triangulation design is less time consuming. Since data can be collected simultaneously, there is a shorter period of data collection compared to collecting one set of data first before collecting the next set. A major disadvantage of this study is in the combination of the two different data sets. The data sets must be combined in such a way to give consistency between the results. This type of method makes it difficult to resolve inconsistencies in the results obtained. [128]

The debate as to which method is preferred, qualitative vs quantitative, is an ongoing one, however according to Patton, "…the important challenge is to appropriately match methods to purposes, questions, and issues and not to universally advocate any single methodological approach for all inquiry situations."[126] Not all research questions can be solved using quantitative methods, and the same is true for qualitative methods. For this study, because the question to be answered is a "how" question, I decided that interacting with the participants using qualitative research methods was the best way to address the overall research question.

Rationale for the Qualitative Approach for this Study

The guiding research question underpinning this study is, "how do students' abilities to recollect information about intermolecular forces (IMFs) and transfer that knowledge of IMFs from class to class, as well as their everyday lives, influence their attitudes towards chemistry?" The hypothesis that drives this work is the underlying belief that the more knowledge students are able to remember and transfer from class to class as well as to their everyday lives, the more positive their attitude towards chemistry. Using only surveys or questionnaires will be inadequate to address this research question because the participants' responses to these surveys and questionnaires alone will not be sufficient to explain their thought processes. Qualitative approaches are most appropriate for this study because using open-ended interview questions provide greater opportunities for discussion with the participants and give more insight in to how well students are able to transfer their knowledge about IMFs. Surveys and questionnaires are typically very rigid and fixed in nature and so determining students' abilities to transfer knowledge from class to class, and to everyday life, based solely on their responses to surveys or questionnaires may be challenging. Using open-ended interviews, I will be able to ask students to provide examples based on their responses, and to clarify responses when necessary. By utilizing a qualitative approach, I will not have a large sample size, but I will be able to ask probing exploratory questions to answer the "whys" and "hows" that emerge.

Furthermore, by using a qualitative approach, I will have greater insight into the attitudes of students. Quantitative methods have been used to measure attitudes using a Likert scale, where responses can range from "I really like chemistry" to "I really dislike chemistry." However, these scales cannot probe any further to determine what the student means by "I really like/dislike chemistry." Using open-ended interview questions, I will be able to ask students questions that delve deeper into what they really mean when they say they do not like chemistry and vice versa. I will also be able to pinpoint the specific aspects of chemistry that students enjoy or do not enjoy. I believe these conversations will help me determine how students' abilities to transfer knowledge have influenced their attitudes towards chemistry.

Framework

As researchers, we are inclined to take our beliefs and philosophies into our research, a process that is unavoidable. According to Creswell, there is a connection between the philosophy a researcher brings into a study and the framework that is used in that study.[127] The philosophical assumption that encompasses this study is the epistemological assumption. According to Burrell and Morgan, epistemological assumptions are "…assumptions about the grounds of knowledge – about how one might begin to understand the world and communicate this as knowledge to fellow human beings."[129] Furthermore, Mertens states that this philosophical paradigm assumes that the "data, interpretations, and outcomes are rooted in contexts and persons apart from the researcher and are not figments of the imagination."[124] With the epistemological assumption, the data obtained and conclusions reached by the researcher are based on the participants' views, and the researcher also "relies on quotes as evidence from the participant[s]."[127] Using this assumption, evidence (or data) is grounded in the subjective individual experiences of persons, and quotes from the individuals are typically used as evidence to back claims made by the research.[127]

When executing qualitative studies dealing with human subjects, it is important to have a theoretical framework that guides the study, because this framework helps to determine the type of research question to be asked and how the data collected will be analyzed.[127] The theoretical framework keeps the researcher focused on addressing the research question. Qualitative research is driven not only by the theoretical framework, but also by the conceptual framework. The conceptual framework focuses on how people learn, while the theoretical framework of a study drives the methodology used, how data are collected and analyzed, and ultimately how the data are interpreted. For this study, I decided to use phenomenography for the theoretical framework, and constructivism as the conceptual framework.

What is Phenomenography?

The word phenomenography was first defined by Marton as a type of research that deals with "…description, analysis, and understanding of [individual] experiences…research which is directed towards experiential description."[130] Phenomenography approaches an experience, or phenomenon, from the point of view of the participant. Using this approach, researchers are able to "make statements about people's ideas about the world (or about their experience of it)."[130] Based on Marton's definition, phenomenography is a qualitative approach, as it deals with attempting to make sense of an individual's interactions with certain experiences or situations. According to Booth, this theoretical approach explores the different ways people experience certain phenomena.[130] In order to explore individuals' experiences with a certain phenomenon, more than just surveys and questionnaires should be utilized. Open-ended interview questions, small group interviews and even observations should be used in order to draw out these experiences from individuals.[131]

What is Phenomenology?

Husserl, who is considered the father of phenomenology, viewed phenomenology as a philosophy, which investigates certain phenomena, including "ourselves, other people and the objects around us… [and] the reflection of our own conscious experiences, as we experience them…"[132] In addition to Husserl, Van Manen also contributed to the definition and development of phenomenology. According to Van Manen, "…phenomenology asks for the very nature of a phenomenon, for that which makes it some-'thing' what it is – and without which it could not be what it is."[133] Phenomenology, just like phenomenography, seeks to investigate the experiences of an individual or group of individuals towards a certain phenomenon. Patton states that phenomenological studies focus on "descriptions of what people experience and how it is that they experience what they experience."[126] Even though both the phenomenological and phenomenographical approach investigate the experiences of individuals, using the phenomenological approach, the researcher "describes the lived experiences of individuals about a phenomenon as described by the participants."[134] The same data collection techniques used in a phenomenographical study are also used in a phenomenological study, as surveys and questionnaires are not enough to draw out individual experiences of phenomena.

Why Phenomenography?

Phenomenology and phenomenography are very similar and are both frameworks that can be used for a qualitative study. However, while phenomenology looks to make statements about a phenomenon experienced by a group of people from a researcher's point of view, phenomenography seeks to make these statements while focusing on the points of view of the participants.[135] In addition to this, while a phenomenological study focuses on commonalities among participants, phenomenographical studies focus on both commonalities and differences among the participants.[127] This slight difference in the approaches is important because looking at both the similarities and the differences gives the researcher a more robust understanding of the phenomenon being experienced by the participants, compared to just looking at the similarities.

For this study, I am not interested in making general statements about how or why students transfer (or do not transfer) knowledge of concepts they are taught from course to course, or from a course to their daily lives. I am more concerned with how different students take knowledge gained in their chemistry courses and apply it to other courses and to their daily lives, and how their levels of ability to transfer information influence their attitudes towards chemistry. Phenomenographic research views data from the participants' perspective in order to focus on "how students relate to what they are taught and how they make use of knowledge they already possess."[135] The goal of phenomenographic research, according to Marton, is not to "…classify people, nor is it to compare groups, to explain, to predict, nor to make fair or unfair judgments of people…";

instead, the goal is to "…find and systematize forms of thought in terms of which people interpret aspects of reality…"[130]

I decided on phenomenography as a framework for my research because the data I collect will help me understand more about how students are learning and shed light on the different approaches being used by students to understand concepts in chemistry. [136] The main goal of my study is to describe, analyze and understand experiences of students as they attempt to transfer knowledge from one place to another, and how this ability or inability to transfer influences their attitudes towards chemistry. It is important to describe what is happening during the learning and teaching process to ensure that the teaching/learning cycle evolves into better practices, both for the student and the teacher.

What is Constructivism?

Constructivism can be considered as both an approach that can be used in education and as a learning philosophy.[137] The idea of constructivism has been around for about 60 years, and is based on prior work of both Jean Piaget and Lev Vygotsky.[138] The basic idea behind constructivism is that what we as humans view as knowledge is constructed from a reality that is dependent on an individual's surroundings. Knowledge is "actively constructed by the mind of the learner."[137] Constructivism deals with the question of **how** knowledge is acquired, and according to Larochelle and Bednarz, "knowledge cannot be transmitted… it is constructed, negotiated, propelled by a project, and perpetuated for as long as it enables its creators to organize their reality in a viable fashion."[139]

In the overarching sense of the word, constructivism is a theory that operates under the idea that individuals construct their understanding and knowledge of the world based on their experiences, or interactions with the world around them.[140] According to Crotty,[141] constructivism "points out the unique experiences of each [individual]" and also "suggests that each [individual's] way of making sense of the world is as valid and worthy of respect as any other… ."[141] Constructivists understand that there is reality, but they believe that individuals are able to view, or construct this reality in different ways, based on their different formal and informal educational experiences.

Since Piaget and Vygotsky first introduced the idea of constructivism, there have been several interpretations of what constructivism means and the different guiding principles of this theory. For the purpose of this study, I identified with the principles highlighted by the physics education research group at the University of Massachusetts,[142] which I believe succinctly highlight the main tenets of constructivism –

- Knowledge is constructed, not transmitted
- Prior knowledge impacts the learning process
- Initial understanding is local, not global
- Building useful knowledge structures requires effortful and purposeful activities.[142]

Knowledge is constructed, not transmitted

Constructivists believe knowledge cannot be transmitted from one source to another. A teacher cannot place knowledge into a pupil; the mind of the learner takes information provided and uses that information to construct knowledge. This construction is based on several factors, including the environment and past experiences of individuals, and because each individual has different experiences, the knowledge that is constructed is diverse. According to Patton,[126] "…constructivists study the multiple realities constructed by people and the implications of those constructions for their lives and interactions with others." Kafai and Resnick[137] believe that with constructivism comes diversity because the individual learner can connect and construct knowledge using a variety of different ways. Since there is diversity in the way individuals construct knowledge, the knowledge construction process is not only complex, it is also subjective.[134] This is important to note because it ties in well to the theoretical framework I have chosen for this study – phenomenography. This framework not only looks for the similarities among the participants, it also highlights the differences in the experiences of the participants.

This study seeks to investigate the relationship between students' abilities to transfer information and their attitudes towards chemistry. Using a constructivist framework helps me as the researcher recognize that the participants will construct and transfer knowledge in different ways, and recognizing this will help me interpret and make sense of the data collected.

Prior knowledge impacts the learning process

The first sub-question this study seeks to answer is what students are able to recollect about IMFs. I decided to address this question first because I believe students need to remember some information in order to be able to transfer that information. This prior information or knowledge students have is garnered based on previous experiences in classrooms, interactions with peers, instructors and other situations. According to von Glasersfeld,[139] since knowledge cannot be transmitted teachers should not just verbally provide information to students, "… [teachers] will have to speak in such a way as to 'orient' students' efforts at construction [of knowledge]. In order to orient someone, however, you have to have a starting point… [students] can interpret the actions and words of their teacher only according to the empirical and operative abstractions which they have worked out previously."[139] von Glasersfeld argues that in order for students to construct knowledge, the teacher needs to determine what the student knows and then proceed in ways to enhance the learning and knowledge construction process.[139]

Even though this study does not explicitly investigate the effect of the student's prior knowledge on the learning process, the ability to transfer knowledge is influenced by prior knowledge. A student that is able to transfer knowledge from class to class, or from class to daily life, shows a level of understanding of the information, and this indicates learning.

Initial understanding is local, not global

Because construction of knowledge is such a subjective process, an individual's initial understanding of any concept is very personal – local. This principle emphasizes the complexity and subjectivity of knowledge construction in individuals. This is an important concept for me as a researcher to keep in mind, as it will help me make sense of the data I collect. It will also help me frame my findings and discussion based on the idea that even though the participants' responses will not be the same (as they all construct knowledge differently) there will be patterns based on the individual responses.

Building useful knowledge structures requires effortful and purposeful activities.

Since knowledge cannot be transmitted, for an individual to construct knowledge that is useful to them, an effort must be made – both by the teacher and by the individual.

As conceptual knowledge cannot be transferred from a teacher to a student, the teacher's role is to facilitate knowledge construction in students. To enhance this facilitation, teachers need to use words (i.e. lecture), but in addition to lecturing, they must purposefully use activities to facilitate transfer of knowledge. von Glasersfeld suggests "language [words] enables the teacher to orient the student's conceptual construction by precluding certain pathways and making others more likely."[138] As for the students, they can, and should be involved in this process. However, since the knowledge construction process is an individual and subjective one, the activities used by individuals will vary, but there needs to be a concerted effort from the individual to be involved in activities that will help in constructing this useful knowledge.

Just as there are variations in the tenets/guiding principles of constructivism, there are also several variants of constructivism. The specific variant that most closely relates to this study is social constructivism.

What is Social Constructivism?

The guiding principle behind constructivism is that individuals construct knowledge based on their experiences. Social constructivists also believe that knowledge is constructed by individual experiences, but they also believe that social factors and interactions play a role in this construction of knowledge.[124,134,143-145] According to Kim,[146] social constructivism is a paradigm that "…emphasizes the importance of culture and context in understanding what occurs in society and constructing knowledge based on this understanding."[146] I believe in any classroom, knowledge construction cannot fall solely on the shoulders of the teacher nor the individual student. Interactions between the teacher and the individual student, as well as the individual student and other students in the classroom facilitate construction of knowledge.

Social epistemology is a term that is quickly becoming associated with social constructivism. Epistemology, according to Jha and Devi,[147] is "the study of the processes by which beliefs and knowledge are acquired and justified", and social epistemology specifically investigates how knowledge is formed, communicated, and used in a society.[147] Social epistemology and social constructivism claim that learning occurs via social interactions, however, while social epistemology focuses on the process, social construction focuses on the knowledge being constructed.

There are three main types of social constructivism: (1) symbolic interaction, (2) social constructionism, and (3) sociocultural constructivism.[147] Of these three types, sociocultural constructivism is the most focused on social interactions. This type of constructivism relates to Vygotsky's sociocultural theory, which postulates that the learning process is mainly impacted by social interactions – actual interactions between individual learners.[148] Vygotsky believed that the learning process could not be separated from social interactions, and viewed the learning process as a shared one.[148] On the other hand, symbolic interaction focuses on the idea that learning can occur in a social context, but also on an individual level.[147,149] This type of social constructivism highlights each individual's interpretation of an idea, as well as the collective interpretation of a group of individuals, and is commonly used in the schooling system. The final type of social constructivism is the social constructionism – a middle ground between the symbolic interaction and sociocultural constructivism. Social constructionism deals with a group of people with a shared knowledge, and/or language. It does not focus just on the individual, but a group of individuals who have similar views or passions.[147,150] An example of social constructionism would be a group of chemical educators at the Biennial Conference on Chemical Education (BCCE). Individuals attending this conference can interact in several venues like seminars, workshops and informal sessions, but also with materials like worksheets and simulations. They have the ability to interact with a community of chemical educators like themselves.

Of these three types of social constructivism, symbolic interaction closely matches my vision for this study. For this study, I am investigating the individual student's interpretation of a certain idea – intermolecular forces, knowing that there are several social interactions that have influenced this interpretation.[147]

There can be several assumptions regarding social constructivism, but I will focus on the following underlying assumptions based on reality, knowledge and learning.[146-147,151]

- Reality is constructed by human actions. Social constructivism does not believe that there is a predetermined reality, but that the members of the community collectively develop what they believe the realities of their community are. The community that is investigated in this study consists of students taking chemistry courses, and based on this assumption, because the community collectively develops their beliefs about certain ideas, there will be similarities and patterns in the data collected among this community.
- Knowledge is both socially and culturally constructed. Similar to constructivism, social constructivists believe that the individual constructs knowledge through interactions with those in their environment – including their instructors and/or

more skilled peers. Again, because of the similarity in the environment of the participants in this study (their interactions with the same instructors, peers and materials provided for the course), patterns will emerge from the data collected that can be used to make assertions to address the research questions.

- <u>Learning is not a passive activity; it involves more than just an individual.</u> According to Kim, "meaningful learning occurs when individuals are engaged in social activities."[146] In this study, meaningful learning is considered to occur if the students are able to transfer the knowledge they have learnt about IMFs in previous classes to other areas, and by observing the classes and interviewing faculty members, this study seeks to explore the role faculty members play in this learning process.

Why Constructivism?

In the previous pages, I gave a brief overview of constructivism and highlighted some main principles guiding this framework. I decided on constructivism, and more specifically, social constructivism, as a conceptual framework for this study because I believe individuals construct knowledge differently. While investigating students' abilities to transfer knowledge about intermolecular forces (IMFs) both to other classes and to their daily lives I realized that this transfer may look different for every individual student, and in this study, I sought to draw out those different transfer methods and look for similarities and differences among the student participants.

I also believe that individuals are able to build knowledge from a foundation of prior knowledge they have acquired along the way, and so in this study, I investigated student participants' prior knowledge by exploring their abilities to recollect information that they have learnt previously. The research question this study addresses centers on whether there is a relationship between students' abilities to recollect and transfer knowledge, and their attitudes towards chemistry. As a constructivist, I believe that students are only able to transfer knowledge based on knowledge they already have – prior knowledge. The beauty of constructivism is that it appreciates the fact that prior knowledge and constructed knowledge differ among individuals, and seeks to highlight the different ways individuals are able to make sense of factual information, which is the aim of this study.

The main idea behind social constructivism is that knowledge is constructed through social interaction. I believe the social aspect is a very important part of learning, which is why one of the sub-research questions in this study involves investigating the role faculty members play in facilitating knowledge transfer both to other classes and to the students' daily lives. The classroom environment is an important aspect of learning and classroom observations as well as interviews with faculty members will help to highlight this aspect of social constructivism. Both the constructivist and social constructivist theories have not only shaped the way I teach, they have also shaped me as a researcher, and this has ultimately influenced this study and the research questions it seeks to address.

Purpose of the study and guiding research questions

Throughout my career as a graduate student, the attitudes students have towards chemistry have always been of great interest to me. The overall purpose of this study was to investigate the relationship between students' abilities to transfer knowledge and the relationship between these abilities and their attitudes towards chemistry.

The initial goal of this study was to answer the question, “how do students’ abilities to recollect and transfer knowledge from the classroom to everyday life influence their attitudes towards chemistry?” Since it would be impossible to address every concept that is taught in chemistry, I focused on the concept of intermolecular forces (IMFs), because this is a basic concept upon which more advanced concepts like solubility and chemical bonding are built. Intermolecular forces relate to physical and chemical properties (boiling points, miscibility, and acid/base chemistry for example), and is one of the most important foundational concepts in chemistry, upon which higher level chemistry content builds. However, after the first round of interviews, I realized that students found it very challenging to transfer the knowledge of IMFs to their daily lives, and so I decided to include transfer to other classes as well as to their everyday lives. This change gave rise to a modified overall question, “how do students’ abilities to recollect information about intermolecular forces (IMFs) and transfer that knowledge of IMFs from class to class, as well as their everyday lives, influence their attitudes towards chemistry?”

To answer this overarching question the following focal points of the research were developed:

- What are students able to remember about IMFs?
- How are students able to transfer what they have learnt about IMFs to other classes and to their daily lives?
- How do additional courses influence this transfer of knowledge of IMFs to their daily lives?

- What is the relationship between recollection and transfer, and their attitudes towards chemistry?

As I began collecting data to address the overall research question, I thought it would be interesting to do a related project investigating the role professors play in facilitating knowledge transfer in the students as well. The final focal point that this study addressed was:

- What are some teaching strategies used by professors teaching freshman and sophomore level chemistry courses to facilitate transfer of knowledge between classes, as well as from class to students' daily lives?

This final question specifically addresses the role professors play in facilitating knowledge transfer. Since learning is a process that involves both the student and the professor, it is important to address the question of knowledge transfer, both from the students' points of view, and from the professors' points of view.

Evolution of the guiding research question

Initially I wanted to investigate students' abilities to transfer knowledge from three major concepts in chemistry – acid/base theory, intermolecular forces and elementary thermodynamics, both forward (to more advanced chemistry courses) and backwards (to previous chemistry courses they had taken). I remember having lunch with my advisor to discuss these ideas, and the only thing I remember leaving that meeting with was the thought that has been continually drummed into my head for what seems like my entire graduate career… "Narrow your research question down."

It took several meetings and a few threats from my advisor, but I finally narrowed down my research question. I focused on one of the three content concepts I chose originally, and instead of looking at both forward and backward transfer abilities, I decided to go with forward transfer. As a researcher, narrowing down my research question and focusing on one concept helps me concentrate on investigating a specific area thoroughly and in an in depth manner. With a very broad research question, I would superficially investigate several different concepts; investigating multiple areas comprehensively takes significant time and resources – luxuries that Ph.D. students cannot usually afford.

In addition to narrowing down my research question, I also decided to reduce the population. I had initially identified the population for this study as students in General Chemistry II and Organic Chemistry I classes from across the state of South Dakota, as I planned to collect data from universities statewide. However, after a series of meetings with my advisor, we decided that it would be more appropriate to focus on students at my home university, South Dakota State University (SDSU), because as the researcher (and research instrument), I would have to be present to collect data at all the universities, which again would be time and resource consuming.

Setting

The university where the data were collected is a public, medium-sized, four-year university with high research activity, according to the Carnegie classifications.[152] At this university, there are three main types of undergraduate chemistry courses: one for the honors/chemistry major students, one for the STEM/pre-professional (e.g. medicine, dental, pharmacy) majors, and one for non-science majors. For this study, I decided not to recruit non-science participants because there are more variables in that population that can be a little more difficult to control, compared to the other two types of chemistry courses. The science/pre-professional majors go through the typical sequence of freshman and sophomore level chemistry courses: General Chemistry I (CHEM 112), General Chemistry II (CHEM 114), Organic Chemistry I (CHEM 326) and Organic Chemistry II (CHEM 328). The honors/chemistry majors, on the other hand, experience a different sequence. In the first semester, these students take what can be considered a blended General Chemistry I and II course (CHEM 115) and then in their second semester, they take Organic Chemistry (CHEM 127). For the science/pre-professional chemistry courses, about 500-600 students are enrolled in CHEM 112, about 350 in CHEM 114 and about 300 in both CHEM 326 and CHEM 328. For the honors/chemistry majors, there are about 40 to 45 students enrolled in both CHEM 115 and CHEM 127.

Sample Population

As the focus of this study centered on students' abilities to transfer knowledge about IMFs, I selected a population that had recently experienced formal instruction related to that topic. At SDSU, students first learn of IMFs in CHEM 112 or CHEM 115. The teaching of this topic generally lasts for about five 50-minute lecture sessions in the typical CHEM 112 course. These CHEM 112 lectures consist of digitalized lecture materials and clicker questions, where the professor explains each clicker question after the answers were posted. The class periods were generally lecture based with a few examples, animations and videos to help explain certain areas of IMFs.

In CHEM 115, the concept of IMFs is also usually taught using the lecture style of teaching. The teaching of this topic generally lasts for a little less than one 50-minute class session – about 30-35 minutes is usually spent on this topic. The CHEM 115 lectures also utilized digitalized slides with pictures and tables showing different trends to explain the different intermolecular forces. As CHEM 115 is a smaller class compared to the CHEM 112 class, the professor was able to ask the students questions and expand on the answers given by students.

The sample population for this study consisted of students in CHEM 114, CHEM 127, and CHEM 326. I chose CHEM 114 and CHEM 127 students because they had most recently completed the general chemistry course (CHEM 112 or CHEM 115) and knowledge of the IMFs concept should be fresh in their minds. As for the CHEM 326 students, I chose them to investigate the effect of additional chemistry courses on knowledge transfer to other classes, as well as the students' daily lives, because compared to the CHEM 114 and CHEM 127 students, the CHEM 326 students have had at least one extra semester of chemistry. I included these students because, based on my experience, freshmen and sophomore students generally do not have positive attitudes towards chemistry and I thought it would be interesting to investigate the relationship between the students' attitudes and their abilities to transfer knowledge.

Recruitment and Selection Procedure

In order to recruit participants for the study, I first observed the way the topic of IMFs was taught in CHEM 112 and CHEM 115. After these observations, I obtained instructor permission to visit CHEM 114, CHEM 127 and CHEM 326, gave a brief description about the study and asked all the students that were interested to complete a survey. I also informed the students that a certain number of them would be randomly selected for interviews and those who were selected would receive 10 hours of free tutoring. The type of sampling employed in this study falls under the broad category of purposeful sampling. Purposeful sampling is a qualitative type of sampling that focuses on selecting a relatively small sample size and collecting in-depth information on that sample, to shed light on the question under study.[126] The specific type of purposeful sampling used to select interview participants for this study is criterion sampling.[126] Criterion purposeful sampling is appropriate for this study because it enables me to select a specific population (based on certain criteria) that is able to "…purposefully inform an understanding of the research problem and central phenomenon in the study."[127]

In criterion sampling, the researcher identifies a criterion or a set of criteria that are necessary of participants to answer the research question before collecting data. Once the criteria have been identified, a specific population that meet those criteria is selected and from there the sample can be selected (purposeful sampling).[124,126-127] Based on students' responses to the survey questions, the inclusion criteria were students' attitudes towards chemistry and students' willingness to participate in an interview. The attitudes were separated into three main categories – positive, neutral and negative, and I randomly selected students from each of these categories. I chose students' attitudes as one of the criteria because I wanted to be able to interact with students who maintained a variety of attitudes towards chemistry.

After selecting the criteria, I sorted the survey responses from the students according to their self-reported attitudes towards chemistry (positive, neutral and negative), and based on their willingness to participate in an interview. After the sorting, I randomly selected four students who did not like chemistry, four who had neutral attitudes towards chemistry, and four who liked chemistry to be interviewed. I did this to obtain answers to my questions from different points of view. However, after the first round of interviews, I realized I had significantly more female participants, so I recruited more male participants. This effort yielded more male participants, but the number of female participants compared to the male participants was still higher. There were 15 participants from CHEM 114, 15 participants from CHEM 326, and nine participants for CHEM 127. A total of 39 students participated in the interviews and 14 (36%) of them were male. The necessity in recruiting more males was to achieve a balanced gender representation in the sample population. I believe this balanced representation in this study is important because from my classroom observations, there was not an obvious overwhelming ratio in favor of either gender in the classroom. A balanced representation would also help eliminate gender bias within the study.

Table 3.1 indicates the demographics of the participant sample used in this study.

Table 3.1. Demographics of Sample Population

Class	Male	Female
General Chemistry II (n=15)	5 (33.33%)	10 (66.67%)
Organic Chemistry I (n=15)	7 (46.67%)	8 (53.33%)
Organic Chemistry H (n=9)	2 (22.22%)	7 (77.78%)

To answer the final research question, “What are the teaching strategies used by professors when teaching freshman and sophomore level chemistry courses that facilitate transfer of knowledge between classes, as well as from class to students’ daily lives?”, I interviewed the faculty members who taught in the specific classes that I observed or from which students were recruited. The type of sampling employed was also purposeful, as I specifically recruited teachers that taught the classes I observed.[126] I recruited faculty members that routinely taught CHEM 112, CHEM 114 (the same professor typically teaches the General Chemistry course sequence), CHEM 115 and CHEM 326. I did not recruit the professor who taught the CHEM 127 course because at the time the data were collected, he was my advisor, which posed a potential conflict of interest that may have introduced bias into the data set.

Table 3.2 shows demographic data of the faculty member participants. All three of the faculty members that were interviewed were males.

Table 3.2. Demographic data for faculty members

Faculty Member	Courses generally taught	Years of teaching experience
Dr. Zazu	Organic chemistry (graduate and undergraduate level)	35 years
Dr. Mufasa	General chemistry courses for science majors	16-17 years
Dr. Pumbaa	General chemistry courses for science majors, chemistry majors and honors students	6 years

Students and faculty members who agreed to participate were provided an overview of the project and an information sheet describing their rights as human subjects, pursuant to human subjects' protection and the Institutional Review Board (IRB). They were also told that they would be referred to by pseudonyms and that their responses would not affect them in anyway, as only I would be privy to their information. The approval letters from the Office of Research/Human Subjects Committee, permitting me to collect data for this study, can be found in Appendices A and B.

Data Collection

Qualitative data falls into four main categories: observations, interviews, documents and audiovisual materials, while quantitative data consists mainly of surveys, questionnaires and standardized assessments.[124,127] Concurrent triangulation strategy was used for the first part of the data collection process. The data consisted of observations (qualitative data) and surveys (quantitative data). For this study, data were generated from classroom observations, surveys, interviews, and artifacts (in the form of documents written by students when attempting to answer certain interview questions). I used classroom observations (observation protocol can be found in Appendix C) to discern the type of instruction students received and to describe the type of classroom environment where the instruction took place. Surveys provided the overall attitude of the class towards chemistry, while artifacts provided students' thought processes. Interviews allowed for probative questioning of students based on their responses to surveys.

According to Marton, it is possible to determine an individual's perception of certain phenomena by using open-ended interview questions.[153] Open-ended interview questions allow the participants to discuss the phenomenon in question as they wish to discuss it, which reveals, in their own words, their perceptions of the phenomenon. For the purpose of this study, I opted to use a semi-structured interview process, which Patton refers to as "the interview guide."[126] In this type of interview, the interviewer has a list of questions to ask all participants, but this list serves as a guideline to assist the interviewer in collecting the needed data. However, with this type of interview protocol the interviewer can freely converse with the participants and ask probative follow-up questions as they evolve. In other words, a semi-structured interview process "… is neither a free conversation, nor a highly structured questionnaire. It is carried through following an interview-guide, which rather than containing exact questions focuses on certain themes."[154] The interview guides for this study can be found in Appendices F and G.

Initial data collection procedures for this study included observing CHEM 112 during lectures where the concept of IMFs was taught. In this class, IMFs were taught in the middle of the semester for five 50-minute class periods. I also observed how IMFs were taught in CHEM 115. The concept was taught near the end of the semester, covering two class periods for a total time of about 30 minutes. I sat in the CHEM 112 class for the five class periods and the CHEM 115 class for the two class periods hoping to address the following questions:

- How is the concept of IMFs being taught (lecture notes, digitalized notes, or other methods)
- Does the teacher link the concept to the real world?
- How much time does the teacher spend on the topic?
- What kinds of examples does the teacher give in relation to IMFs?

These questions were put together to determine the different methods used by the instructor to teach the concept of IMFs. During these observations, I took field notes on the following:

- how different methods of instruction were used to teach the concept of IMFs in CHEM 112,
- how each professor linked the concept of IMFs to the real world and/or gave tangible examples to which the students could relate,
- how much time each professor spent on the topic of IMF.

These observations provided a baseline of the instruction the participants received, and what they should know about IMFs after leaving the General Chemistry I class.

After my observations in CHEM 112 and CHEM 115, I asked the professors that taught CHEM 114, CHEM 127 and CHEM 326 for permission to come into their classes to recruit students. At the beginning of the class period, I informed the students of the purpose of my study and invited them to participate in an online survey to which the professors had agreed to post on the webpage for the classes. The questions in the survey can be found in Appendix E. I first recruited students in CHEM 114 and about 30% of approximately 300 students took the online survey. However, in CHEM 326, there was very little response from my initial in-class recruitment visit – only about 3% of 300 students responded. To solicit greater participation, I printed out copies of the online survey and distributed them in the co-requisite lab course. This approach provided the students who were willing to participate the time to fill out the surveys immediately, rather than taking time out of their busy schedules to complete it online. This direct method of recruitment increased student participation (65% of the 300 CHEM 326 students filled out the surveys); the same method was employed to recruit students from CHEM 127, and 73% of the 30 CHEM 127 students filled out the surveys. Based on the responses to the surveys and a random selection process, I sent emails to individuals who met the criteria to participate in the interview portion of the study. I then arranged times to meet with the individuals who responded to my initial email inviting them to participate in the interview process.

The interviews lasted between 20 and 30 minutes and the interview protocol used can be found in Appendix F. These interviews were designed to help answer the question, “how do students’ abilities to recollect information about intermolecular forces (IMFs) and transfer that knowledge of IMFs from class to class, as well as their everyday lives, influence their attitudes towards chemistry?” All interviews were audiotaped using both a personal computer and a digital audio recorder. I used two different ways to record the interviews to ensure that I always had a backup. Prior to the beginning of each interview, the participants were asked to sign the informed consent form.

In addition to interviews, surveys and observations, I collected documents throughout the course of the study. One document was my journal. I took field notes about the observations of CHEM 112 and CHEM 115, and during the interviews with students. Annotated notes from interviews, like details about the participant’s body language when working through a problem, helped me remember things I would not have remembered from transcribing interviews alone. In addition to my journal, the second interview question under the heading “How are students able to transfer what they have learnt about IMFs in general chemistry I to their daily lives?”, required the participants to write down their answer to a certain problem solving question, in addition to describing their thought process. The sheet on which they wrote their thoughts also serves as a document for analysis in this study.

Table 3.3 below gives a brief summary of the different data sources used in this study and the information obtained from those sources. After the interviewing process was complete for each participant, the audio files were saved on a personal, password-protected computer and were transcribed verbatim. These transcripts were also saved on the personal computer for analysis.

Table 3.3. Data sources and their uses.

Data Source	Information Obtained
Classroom Observations	Classroom environment and teaching style of professor
Surveys	General demographic information Student attitudes towards chemistry
Interviews	Level of recollection of students Transfer abilities of students Student attitudes towards chemistry
Journal	Mannerisms of participants (students and instructor)
Artifacts	Level of recollection of students

To address the secondary research question, "What are the teaching strategies used by professors when teaching freshman and sophomore level chemistry courses that facilitate transfer of knowledge between classes, as well as from class to students' daily lives?" I interviewed the three faculty instructors, again using the semi-structured interview method.[126] The interview protocol can be found in Appendix G. The interviews took approximately 30 minutes each, and were recorded using a digital audio recorder. After the interviews, the recordings were transcribed verbatim and the transcripts were again saved on my personal computer for further analysis.

Timeline for project

Table 3.4 shows the timeline for the implementation of this study. The overall research question was finalized during the spring 2014 semester and IRB approval was obtained over the summer 2014 semester, so that data collection could commence in fall 2014. Data collection continued through the fall of 2015. Preliminary data analysis began via the process of transcribing the interviews in winter 2015, and concluded in summer 2016.

Table 3.4. Timeline for study.

Process	Time period
Finalization of research question	Spring 2014
IRB approval	Summer 2014
Observations in CHEM 112	Fall 2014
Participant recruitment and data collection in CHEM 114	Spring 2015
Participant recruitment and data collection in CHEM 326	Fall 2015
Observations in CHEM 115	Fall 2015
Participant recruitment and data collection in CHEM 127	Spring 2016
Data analysis	Spring 2015 – Summer 2016

Data Analysis

According to Patton, "the challenge of qualitative [data] analysis lies in making sense of massive amounts of data… [it] involves reducing the volume of raw information, sifting trivia from significance, identifying significant patterns, and constructing a framework for communicating the essence of what the data reveal."[126] Data analysis in qualitative research is an ongoing, iterative process that starts even before the end of data collection for a study.[124] To reduce the "massive amounts of data"[126] several stages were passed. Mertens discusses different principles/ideas that guide most qualitative research analyses and I have attempted to summarize these ideas below to focus on how the data for this study were analyzed.[124]

1. The first thing to note about data analysis for qualitative studies is that it is an ongoing, iterative process, which occurs from the data collection phase until the end of the study.
2. The general idea behind the analysis of qualitative data is starting from a large set of potentially confusing data and systematically reducing the data to smaller,

more comprehensible parts. This is also known as inductive analysis, which involves "discovering patterns, themes, and categories in one's data."[126] Inductive analysis focuses on themes and patterns that emerge from the data based on the researcher's continuous interaction with the data set.[126]

3. Analysis should be an organized and logical process, but certainly not a rigid one. There is no statistical test that tells qualitative researchers when data analysis is complete; data analysis is complete in a qualitative study when the researcher begins to encounter repetitive themes emerging from the data.
4. The data analysis process is also reflective, as the researcher is always ensuring that the results are an accurate reflection of the data collected, and of the perceptions of the participants. There are several ways a researcher can do this, and these will be further discussed in the "Validity and Reliability" section of this chapter.
5. Themes and categories are built by comparing the data. Similarities and differences in the data are noted and based on these ideas, several themes/categories can be highlighted. It should be noted that these categories are not rigid and may be refined as the analytic process progresses.

For this study, data analysis began once I started the interviewing process, indicating the ongoing process of the analysis. As I started transcribing, I began to get a general sense of what my data looked like, and realized that even though I had plenty data from the interviews, I needed to reduce the data and begin to highlight the similarities and difference in the data. As the transcription process continued, ideas for themes and ways to categorize the data started to form in my mind. Keeping the third stage of the analysis in mind, I knew that I was not going to come up with all the themes and categories in one trial, and so I kept combing through the data (iterative process) in an organized fashion to ensure the completeness of the data analysis. After working through the five stages highlighted above several times I decided to split the analysis into three main themes:

- Recollection
- Knowledge transfer
- Affective domains (attitudes, motivation to learn chemistry, perceived relevance of chemistry)

Recollection

I made a decision tree and came up with categories based on this tree. A detailed description of how the decision tree was developed and how the recollection categories were established can be found in CHAPTER 4 (Results). From their responses, students were sorted into four different recollection categories – high level of recollection, moderate level of recollection, minimal level of recollection, and no recollection. The responses were first analyzed by class (CHEM 114, CHEM 127 and CHEM 326); similarities and difference were drawn from the participants' responses. Following analysis by class, the results were then compared among classes, again highlighting the similarities and differences.

Knowledge transfer

Again, a decision tree was used to determine categories based on student responses. A detailed description of how the decision tree was developed and how the knowledge transfer categories were established can be found in CHAPTER 4 (Results).

The knowledge transfer theme was split into two sub-themes: knowledge transfer to daily life and knowledge transfer to other classes. From the students' responses, there were four categories of transfer for each sub-theme – high level of transfer, moderate level of transfer, minimal transfer and no apparent transfer. The data were first analyzed by class and then the results obtained were compared among the three classes.

Affective domains (attitudes, motivation, perceived relevance)

The final theme for this study dealt with affective domains, specifically students' self-reported attitudes towards chemistry, their motivation for learning chemistry and their perceived relevance of chemistry to their daily lives. From the data obtained, the participants' attitudes fell under the following three categories:

- Positive,
- Neutral,
- Negative.

Their perceived relevance of chemistry also fell under three categories:

- Relevant,
- Relevant to future career,
- Not relevant.

Their motivation to learn chemistry fell under the following three categories:

- Motivated to learn because of interest in the subject,
- Motivated to learn because chemistry is needed for their major,
- Not motivated to learn.

Student responses were sorted using the categories stated above.

The themes were continually refined until I was able to come up with a cohesive set of codes (categories) that accurately reflected my data set. More explicit detail about how the themes were generated for the data sets and how the categories were created and defined can be found in CHAPTER 4 (Results).

Validity and Reliability

I like to think of the "validity and reliability" section of a paper as the, "give us (the readers/reviewers) reasons not to throw this whole study into the garbage can" section. Regardless of how interesting a study is, if the methods used to collect and analyze the data are questionable, the quality of the study and strength of the claims made in that study are immediately called into question. For the quality of the study to be proven, 'the researcher must establish indicators that provide evidence that the information generated in the research is trustworthy and believable."[124]

Validity is defined as "the extent to which [an instrument] measures what it was intended to measure,"[124] where the instruments in this study were the interview protocols/surveys. On the other hand, reliability is "the extent to which research findings can be replicated", and still give similar results.[124] In order to ensure the validity and reliability of this study, I used a few strategies.

A strategy often used to enhance the validity of qualitative studies is "triangulation," which means using multiple sources of data in order to strengthen the results.[124,127] One challenge faced in qualitative studies is whether the results obtained truly reflect what was measured. In order to combat this problem, data were collected using multiple sources – observations, surveys, interviews and artifacts, and the data from these sources were used to support the findings in the study. For example, during my interviews with the faculty participants, I asked a question about what techniques they used in trying to facilitate transfer from class to daily lives in their students. I was able to compare the responses given in the interviews to the data I obtained from my observations and make assertions based on the different data types.

During the classroom observations, I was aware of what the students were learning in the class and this helped inform the types of questions asked of students during the interviews. In the surveys, students answered multiple-choice questions, and during the interviews, I was able to ask probative questions that made the students further expound on their answers to the survey questions. The students' responses to the survey questions were the same when I asked them the identical questions during the interview, which speaks to the reliability of the data sources.

In addition to triangulation, I also used "member checking," a process that seeks to enhance the validity and credibility of the study by seeking the participants' views.[127] After transcribing all the interviews, I summarized the transcripts for each participant, highlighting the main ideas, emailed these transcripts to them and asked them if the summary accurately represented their views. By doing this, I ensured that my interpretation of the responses given by the participants was accurate; that is, I was able to clearly grasp what they were trying to say, and was true to their original intent.

Further, as I developed the codes during analysis, I discussed my codes and emergent findings with graduate students in the chemistry department who were not involved in chemistry education (CHEMED) research, and CHEMED faculty members to ensure that the findings were valid and rooted within the data collected. I first presented condensed versions of the interview data, codes and the general results to the individuals separately and asked them to go through the documents. I then met with the individuals to obtain their feedback on the codes, how the data were grouped and the emergent results. This process is called “peer examination” or “peer review,”[127,141] which increases the validity of qualitative studies by providing the researcher honest external views about the findings of the study. The individuals I discussed the codes and findings with were in agreement with how the data were coded and the findings these codes produced.

To improve the reliability of this study, detailed descriptions of methods, techniques and site where the study took place were provided. Giving detailed descriptions about the study strengthens the reliability because doing so “enables readers to transfer information to other settings and to determine whether the findings can be transferred,” based on similarities in the characteristics of the populations being compared.[127] In addition to providing detailed descriptions to enhance the reliability, I also used the inter-coder reliability method.[127] I enlisted the help of a chemistry professor who had taught the topic of IMFs for over a decade to assist with the coding of the data. The reliability coefficient between the coders was 0.86 out of 1, which is an acceptable number for a qualitative study.[124]

Role of the Researcher

As a qualitative researcher, in this study I played the role of the instrument.[126-127] My background as a Chemistry Education student has exposed me to different types of educational research, including qualitative research. I obtained my master’s degree in chemistry, with my thesis focused on a qualitative based study, and I am currently working on my Ph.D. in chemistry and my research focus is also qualitative. Over the course of working on these degrees, in addition to graduate level chemistry courses, I have taken multiple education courses that focus on qualitative and quantitative styles of research. I have also interviewed students, both for my master's project and as part of several graduate level courses, in an attempt to answer certain research questions. My interview experiences enabled me to ask probing question during the interview process, which helped give a richer data set with a lot of information from the participants.

In addition to this, my background in both chemistry and education enabled me to design the research protocol used in this study. Based on the research question for this study, I knew that the semi-structured interview process was the best way to address the question, and because of my chemistry knowledge, I was able to create an instrument with questions that were able to separate students based on their abilities to answer the questions.

As a chemistry graduate student, as well as someone with several years of experience as a teaching assistant, I have developed a more in-depth understanding of the concept of IMFs, as I have been continually pushed to understand the concept more, the further I go in my study of chemistry. This in-depth knowledge of IMFs helped me make sense of the chemistry terminology used by the students and to ask more probing questions to determine the extent of the students' knowledge of the concepts of IMFs, something a researcher unfamiliar with chemistry concepts would not be able to do.

My role as a researcher in this study also extended to analytic methods to make sense of the data obtained, to be able to draw out themes, similarities and differences in the data collected. My background in qualitative research has enabled me to do this. As qualitative research is an area I have worked in for a little over four years, I understand what needs to be done with the data collected. I recognize that data analysis is an iterative process that takes is time intensive. In order to draw out similarities, differences, and accurate, cohesive themes from a data set, a great deal of patience is required. Since I have experienced this process before, I know what it will take to analyze the data. In addition to being knowledgeable about the data analysis process, I also have experience in communicating the results. I have learnt that it is necessary to be very concise and specific in discussing the results from a qualitative study. I have also learnt that it is important to support results and conclusions with data from the participants. All these skills and experiences discussed above will help me to successfully carry out and report a valid and reliable study.

Researcher Bias

I have tried to address some of the biases that may be present in this study by providing ways to enhance the validity and reliability of the study, however, I believe it is important to highlight the beliefs and perspectives I brought into this study. One of the beliefs was that prior knowledge would influence the individual's ability to transfer knowledge. I believe that the more an individual is able to remember, the more likely it is for that individual to use that knowledge in other areas. Another belief was that there would be a positive relationship between an individual's ability to transfer knowledge and their attitudes towards chemistry. If a student is able to retain knowledge and apply it to other areas outside of the class where the information was learnt, the individual would be more likely to have a favorable view towards the subject (chemistry).

In addition to these beliefs, as a constructivist, this study was conducted through the lens of social constructivism. I believe that students construct knowledge based on different personal experiences, and that social factors, including the influence of the instructors, can affect the way students learn and construct knowledge. These beliefs may have influenced this study in the way the data were collected, the instruments used and ultimately, the conclusions drawn.

CHAPTER 4: RESULTS

Introduction/Overview

The overall goal of this project was to determine whether a relationship exists among the following variables:

- students' abilities to recollect information about intermolecular forces (IMFs)
- students' abilities to transfer information about IMFs from their general chemistry class to other classes, as well as to their daily lives, and
- students' attitudes towards chemistry.

If relationships among the variables mentioned do exist, the second goal of the project was to describe such relationships. In order to address these goals, the following sub-research questions guided the study:

- What are students able to remember about IMFs?
- How are students able to transfer what they have learnt about IMFs to other classes, and to their daily lives?
- How do additional chemistry courses influence this transfer of knowledge to daily life?
- What is the relationship between recollection and transfer and their attitudes towards chemistry?

In this section, I will provide a general picture of each subject sub-population used in this study by describing the demographics based off the survey responses. I will then discuss the results for each sub-research question based on analysis of the collected data.

Demographic information of the participants (survey responses)

Data were collected from three different classes – CHEM 114, CHEM 127 and CHEM 326. Surveys were administered to volunteer participants to collect demographic data. In CHEM 114, the surveys were administered electronically – a link was provided on the class website. The total number of CHEM 114 respondents was 72 out of about 300 students, yielding a 24% response rate. For both CHEM 127 and CHEM 326, paper copies of the surveys were administered in class/lab and the total numbers of respondents were 22 of about 30 students, and 195 of about 300 students respectively. The response rates for CHEM 127 and CHEM 326 were 73% and 65% respectively. Surveys were administered during the third and fourth weeks of the semester. Typically, by this time in the semester both the students and professors have settled into a routine and have started talking about material for the course instead of just reviewing material learnt in previous classes. The survey questions (Appendix E) were as follows:

- What is your major?
- What is your year of study?
- Why are you taking this chemistry class?
- How do you feel about chemistry in general?
- How do you feel about the class you are in presently?
- Do you think chemistry is relevant to you as a person?

Survey results

What is your major?

Figure 4.1 shows the results of programs of study by class. In CHEM 114 (n=72) and CHEM 326 (n=195), the majority of the students were pre-professional majors (43

(60%) and 129 (66%) respectively). Examples of pre-professional majors included pre-medicine, pre-pharmacy, pre-dental and pre-veterinary. Second to the pre-professional majors, science majors were the most likely to take CHEM 114 and CHEM 326 (11 (15%) and 45 (23%) respectively). Examples of science majors included biology, microbiology, and physics. Since engineering majors are not required to take CHEM 326 at this university, this is a likely explanation for the absence of engineering majors in CHEM 326. In CHEM 127 (n=22), half of the students were pre-professional majors, while the other half were science majors.

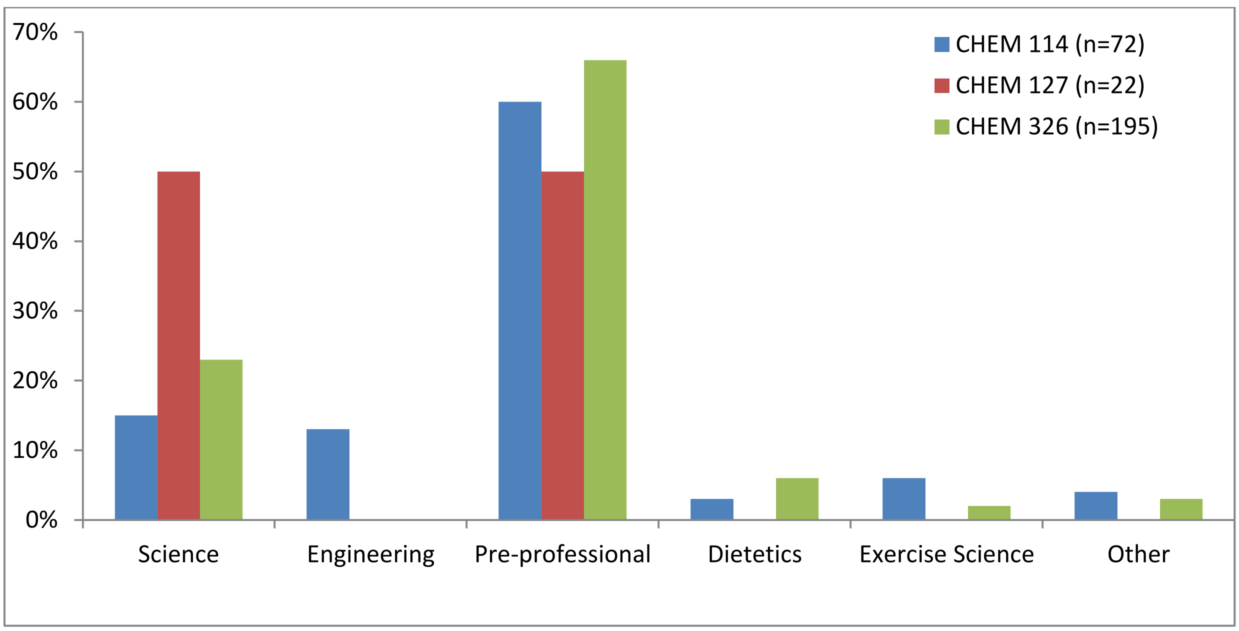


Figure 4.1. Information about majors for CHEM 114 (n=72), CHEM 127 (n=22) and CHEM 326 (n=195).

What is your year of study?

As shown in Figure 4.2, CHEM 114 (n=72) and 127 (n=22) consisted of mostly freshmen (54 (75%) and 19 (86%) respectively), which is probably because these two courses are usually taken in the first year of a student's career. Most of the CHEM 326 students were sophomores (127 (65%) of 195), because this course is usually taken in the second year of the student's academic career.

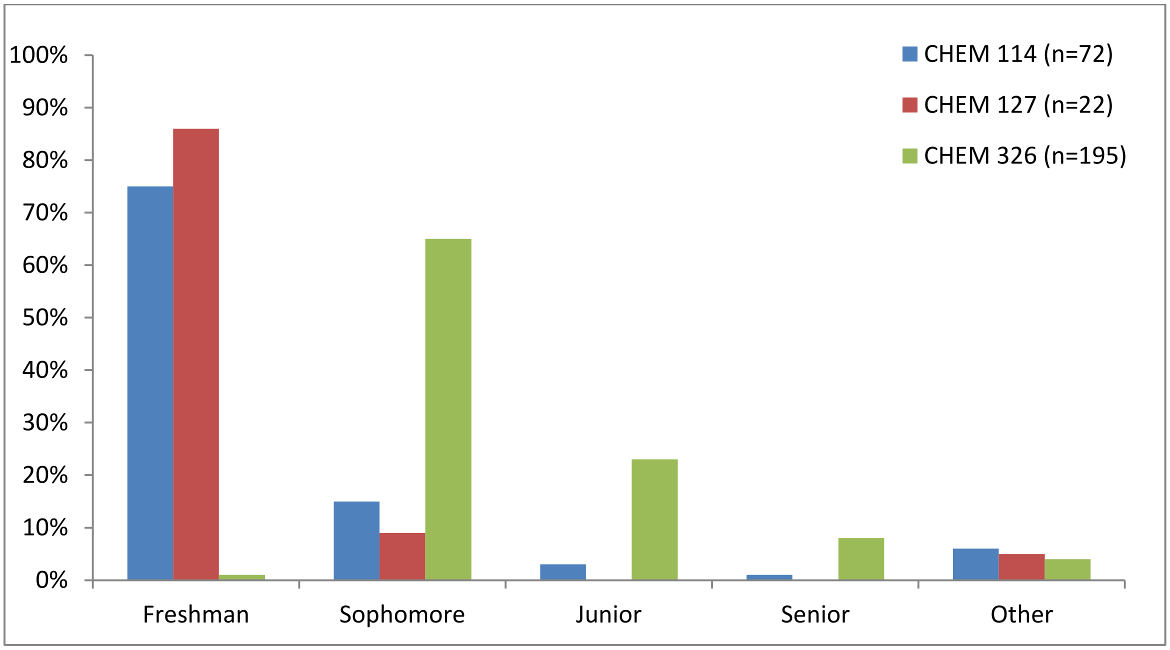


Figure 4.2. Year in school information for CHEM 114 (n=72), CHEM 127 (n=22) and CHEM 326 (195) students.

Why are you taking this chemistry class?

This question was asked to obtain information about why most of the students were enrolled in their current chemistry class. Not surprisingly, the majority of students in all three classes were taking the class to fulfill a major requirement. In CHEM 114, 64 (89%) of the 72 students took the course to fulfill a major requirement. In CHEM 127, 14 (64%) of the 22 students took the course to fulfill a major requirement, while 160 (82%) of the 195 CHEM 326 students took the course to fulfill a major requirement. The six students (27%) who fell under the 'other' category in CHEM 127 selected multiple choices (as this was a paper survey, not electronic, the students were able to shade in multiple boxes), including ‘to fulfill a major requirement’. Figure 4.3 presents a graphical representation of this information.

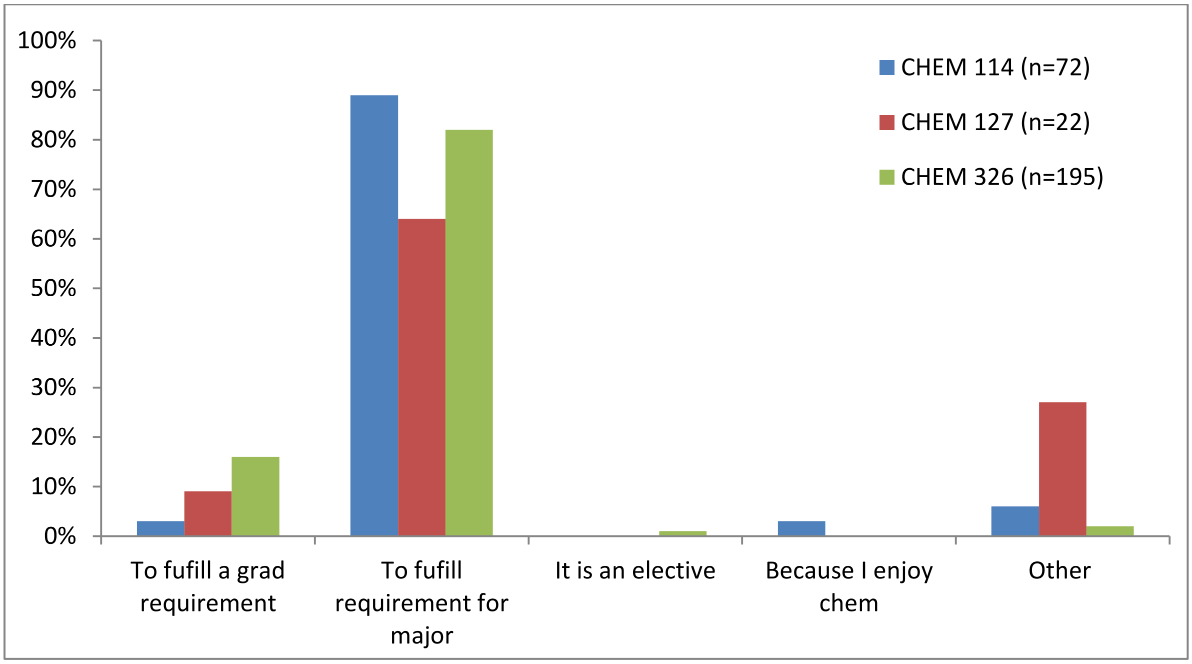


Figure 4.3. Purpose for taking current class (CHEM 114, CHEM 127 or CHEM 326).

How do you feel about chemistry in general?

To address this question in the survey, the following statement was ranked by the students, “I like chemistry very much,” with responses based on a 5-point Likert scale. Figure 4.4 shows the student responses. In all three classes, at least half of the students reported that they liked chemistry (CHEM 114 – 41 (57%); CHEM 127 – 17 (77%); CHEM 326 – 98 (50%)). Interestingly, none of the students in CHEM 127 reported that they disliked chemistry. Ten (14%) of CHEM 114 students and 41 (21%) of CHEM 326 students indicated that they disliked chemistry. This could be due to multiple factors, including high school chemistry background, the sizes of the classes or the methods of instruction used by the instructors.

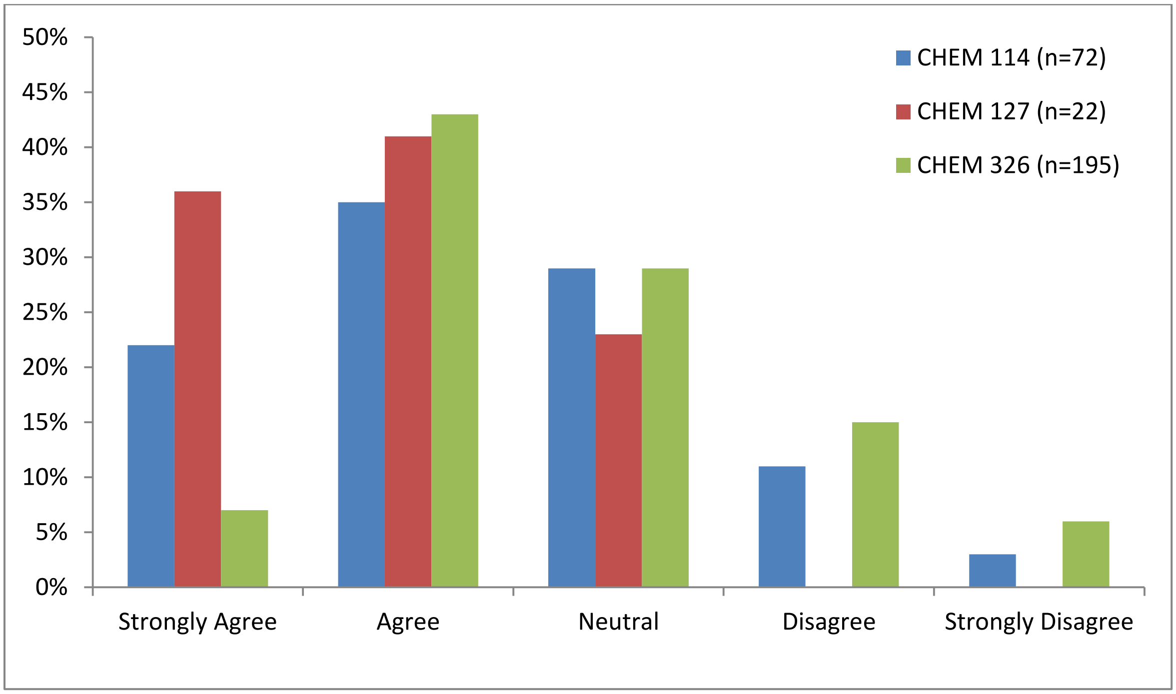


Figure 4.4. Student attitudes towards chemistry.

How do you feel about the class you are in presently?

To address this question, the following statement was ranked by students, “I enjoy CHEM (114, 127 or 326)”, with responses based on a 5-point Likert scale. Figure 4.5 shows the student responses. For CHEM 114 and CHEM 127, a majority of the students, 40 (55%) in CHEM 114 and 16 (73%) in CHEM 127, indicated a positive attitude towards the class they were in currently. Seventy (36%) of the students in CHEM 326 indicated a neutral attitude towards the course, while 66 (34%) of them reported negative attitudes towards the course. Compared to the previous question, ‘How do you feel about chemistry in general’, both CHEM 114 and CHEM 127 students had similar responses to both questions. However, in CHEM 326, half of the students (98) stated that they liked chemistry in general, but only 59 (30%) of the same students liked their current class – CHEM 326. From my interactions with several students over the course of my academic career, this result is not surprising. Many students enjoy the math based chemistry classes, as they can do the math and plug numbers in an equation (procedural understanding); however, several students struggle with organic chemistry because it goes beyond mathematical equations and numbers, and actually requires a conceptual understanding of the material.

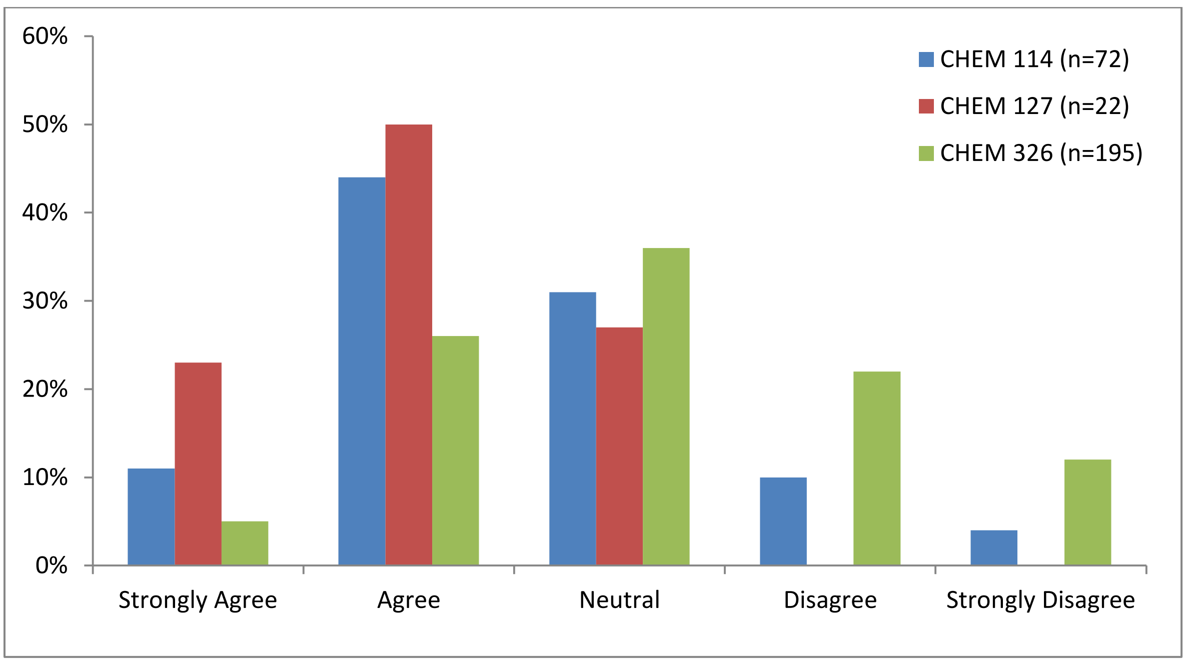


Figure 4.5. Student attitudes towards their specific class (CHEM 114, CHEM 127 or CHEM 326).

Do you think chemistry is relevant to you as a person?

To address this question, the following statement was ranked by students, "I think chemistry is not relevant to my life" and responses were based on a 5-point Likert scale. Figure 4.6 shows the student responses. More than half of the participants in each class believed chemistry was relevant to their lives (CHEM 114 – 53 (74%); CHEM 127 – 17 (77%); CHEM 326 – 125 (64%)). A sizeable portion of second year chemistry students (31 (16%) of 195) agreed with the statement, "I think chemistry is not relevant to my life" – a disturbing observation. This response from 31 of 195 CHEM 326 students indicates that there is still work to be done in terms of communicating the importance of chemistry to daily life to our students.

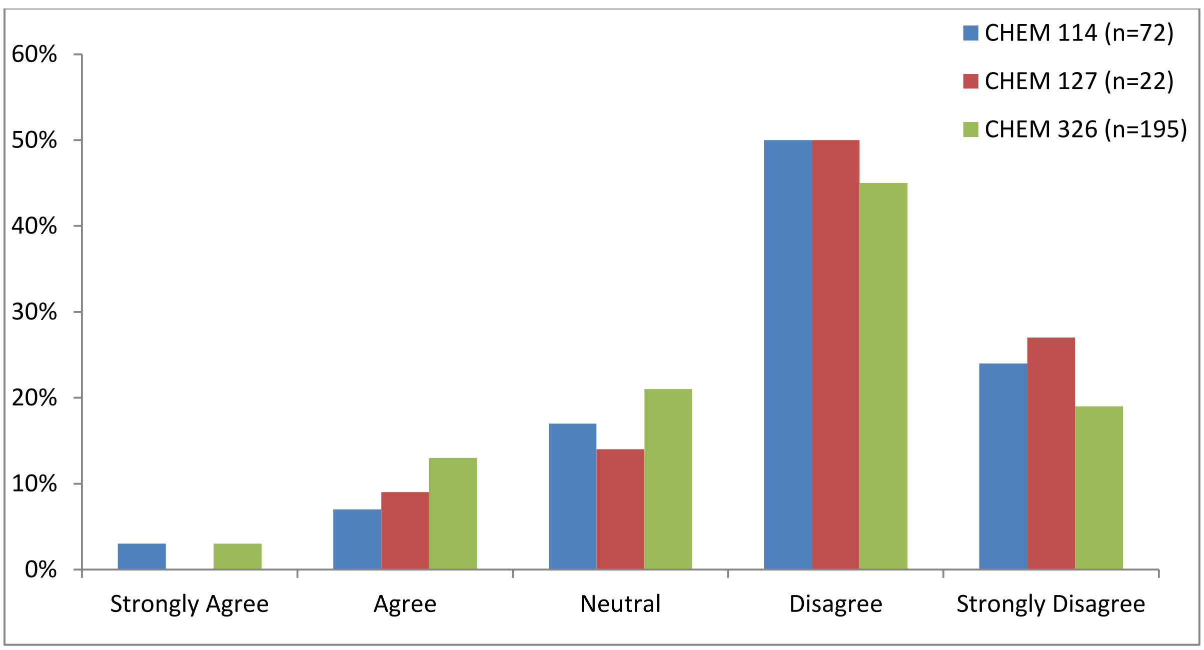


Figure 4.6. Students perceived relevance of chemistry.

Summary of survey responses

The survey results showed that a majority of the CHEM 114 and CHEM 127 students were freshmen pursuing degrees in either a pre-professional field or a science field, while the majority of CHEM 326 students were sophomores pursuing degrees in either a pre-professional field or a science field. The results also showed that a majority of the survey participants in this study self-reported positive attitudes towards the general idea of chemistry. Furthermore, a majority of CHEM 114 and CHEM 127 students had positive attitudes towards their specific courses, while more CHEM 326 students had neutral attitudes towards their specific course. Finally, in terms of perceived relevance of chemistry to their daily lives, a majority of students across all three classes found chemistry to be relevant to their daily lives.

What are students able to remember about IMFs? (Recollection)

Recollection data were gather using interviews, and the interview protocol that provided these data is in Appendix F. Thirty-nine students were interviewed – 15 students from CHEM 114, nine students from CHEM 127, and 15 students from CHEM 326. The following questions were used to assess the student's level of recollection:

- Is the student able to define IMFs correctly?
- Is the student able to give examples of IMFs talked about in class?
- Is the student able to arrange the following molecules in order of increasing boiling point: CCl_4, H_2O and F_2?
- If the student is able to arrange the molecules in the correct order, can they provide a correct explanation?

Of these four questions, I decided the last one – providing the correct rationale for the right arrangement of the molecules, carried the most weight in terms of recollection. As the first two questions involve more memorization than understanding of the material, they both carry the same weight. I decided the third question carried the least weight because the participant may answer the question correctly because of a lucky guess and not because they actually understand the logic behind the question.

The ability of a student to think through a problem and provide a correct explanation for a question requires more than just regurgitation of past knowledge on the part of the student, and this is why the last question carries the most weight. The student's ability to define IMFs and provide examples from class are illustrations of rote learning, and highlight lower levels of recollection, and so these two questions do not carry as much weight. A student may be able to guess how to arrange molecules correctly (lower level of recollection), but providing an accurate explanation shows a higher level of recollection than just defining IMFs correctly and giving examples.

To make sense of the data collected, I elected to use a form of data mining – decision trees. According to the UCLA Anderson School of Management,[155] data mining is "the process of analyzing data from different perspectives and summarizing it into useful information."[155] Data mining is typically used in organizations that seek to find trends in data and use those trends to increase their income and/or reduce their expenditure.[155-156] The general idea behind any data mining technique is to identify trends in a dataset, which is why I elected to use a decision tree. The decision tree helps to create rules, which are used to classify a set of data into different categories in a manner that is logical[157] I established a decision tree from the four questions stated above and the weight each question was assigned. This tree helped me sort student responses into 12 distinct groups of students. Upon further investigation, I was able to group these 12 types of students into four different categories of levels of recollection. Figure 4.7 shows the recollection decision tree.

The starting point on the tree was whether the student was able to define IMFs correctly. A correct definition included the idea of interactions between molecules. Depending upon the initial answer, a divergent path could be taken down the tree with the next question addressing whether the student was able to give examples of IMFs (like hydrogen bonds, van der Waal's forces and dipole-dipole forces) from class. Again, depending on the student's ability to provide examples, divergence in the path occurred. Next, the student's ability to arrange the three molecules ($CCl_{4,}$ F_2 and H_2O) in order of increasing boiling point led to another divergence in the path. The correct order of increasing boiling point is F_2, CCl_4 and H_2O. The water molecule (H_2O) has the highest boiling point because of the three molecules, water is the only polar molecule, and has hydrogen bonding (the strongest of the IMFs) in addition to van der Waals' forces. The carbon tetrachloride molecule (CCl_4) has a higher boiling point than the fluorine molecule (F_2) because even though they both have the same type of IMFs, CCl_4 has more electrons than F_2, and this makes it is more polarizable (more likely to form a dipole), which makes its IMFs stronger compared to F_2. Even though polarizability is the more correct rationale behind why CCl_4 has a higher boiling point compared to F_2, the size of a molecule can also be a good predictor of boiling points. The bigger the molecule, the more likely it is to have a higher boiling point.

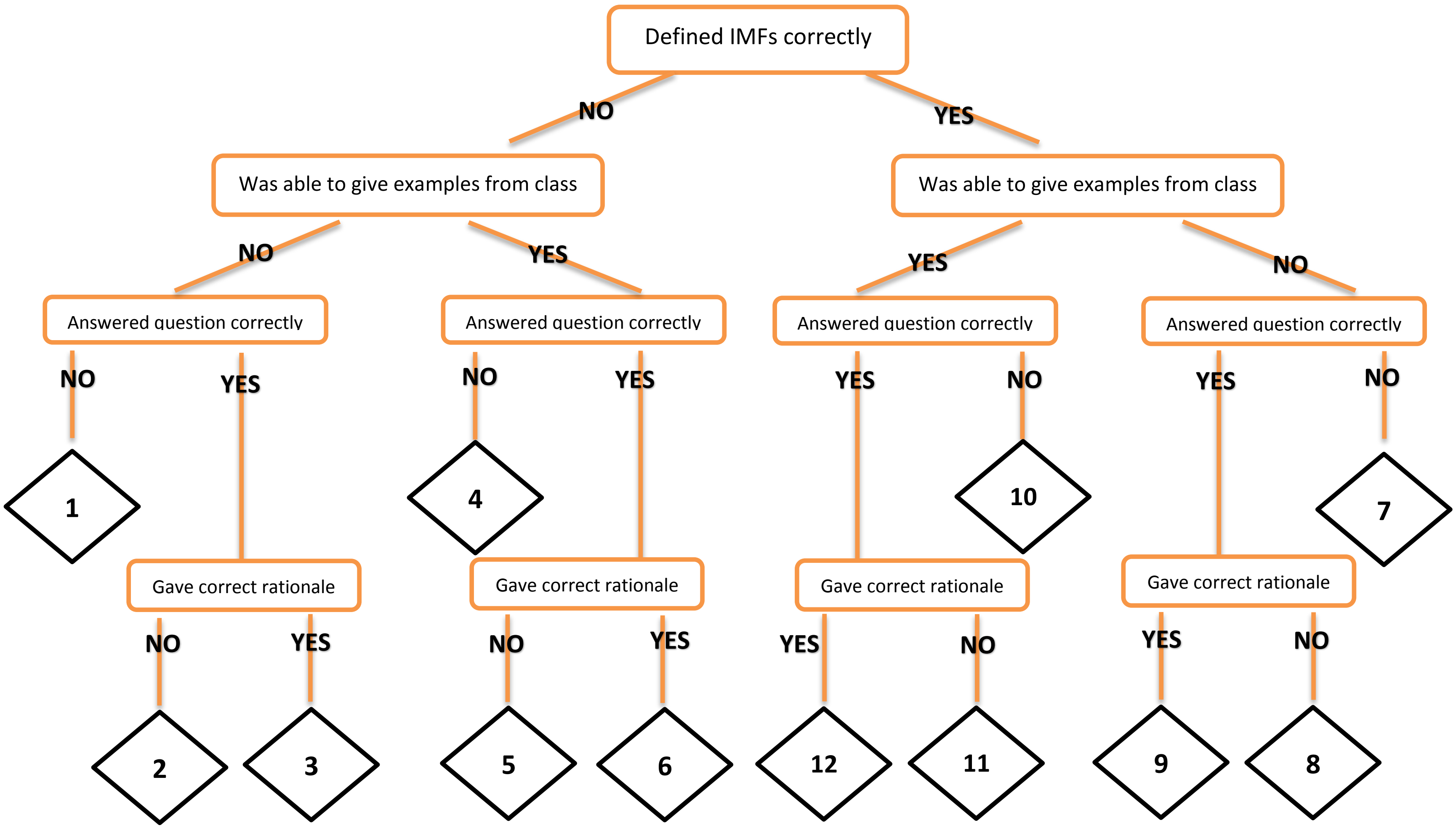


Figure 4.7. Recollection decision tree.

Finally, the student's ability to provide the correct rationale (provided above) for the arrangement of the three molecules led to the final divergence in the path. This final divergence created 12 categories of students as shown in Figure 4.7. These 12 categories of students were narrowed down to four distinct levels of recollection, namely:

- High level of recollection – category 12
- Moderate level of recollection – categories 3, 6 and 9
- Minimal level of recollection – categories 4, 5, 7, 8, 10 and 11
- No recollection – categoreis 1 and 2.

High level of recollection (#12)

Students in category 12 (Figure 4.7) were able to define IMFs correctly, give examples of IMFs from class, arrange the given molecules in order of increasing boiling point and rationalize the correct answer. Of the 39 students interviewed, nine (23%) were in this category. Of the nine students who had high levels of recollection, two were from CHEM 114 (n=15), two from CHEM 127 (n=9) and five from CHEM 326 (n=15). The following quotations from students in this category of high recollection demonstrate their correct categorical placement:

> "…intermolecular forces are like the forces between two molecules, so like dipole-dipole, induced dipole, London dispersion… I guess I remember, um, like the ion-ion is the strongest, London dispersion is the weakest… [I remember] the ion-dipole and like the dissolving of ionic solids in water…H_2O is a dipole polar molecule…H_2O is going to have highest boiling point because it has the strongest bonds…with London dispersion, the greater the mass, the stronger the bonds…" ~ Deji, [32, 34, 38, 42, 45, 49]* CHEM 114 (#12)

> "… [IMFs are] interactions between molecules…hydrogen bonds, Vander Waal's, uh, London dispersion…I put F_2 as the lowest, uh, because it was the smallest…

*Every quote is followed by the participant's pseudonym (e.g Deji) and the statement number(s) from the interview transcripts (e.g. [1-4])

CCl_4 is going to have, uh, Vander Waal's…it's like London dispersion forces and stuff are going to be greater than that of F_2, just because it's bigger in nature…H_2O would boil last because it is polar and has hydrogen bonding, so it's got the most IMFs." ~ Mordecai, [18, 21, 30-31] CHEM 127 (#12)

"…intermolecular is the forces that occur between molecules… Vander Waals' is like oil…interactions between things we think of as oils, long polar, non-polar chains…then ionic is like sodium chloride, hydrogen bonding is water…the intermolecular force…for fluorine would just be Vander Waal's forces, and so the ability to break those bonds doesn't require much energy…I think that [CCl_4] is non-polar, but is heavier than [F_2]…it has a larger surface area, so it will have more Vander Waal forces with the molecule…the stronger version of a dipole intermolecular force is hydrogen bonding, and water has that." ~ Rafael, [20, 23, 28-30] CHEM 326 (#12)

Moderate level of recollection (#3, #6 and #9)

Students in categories three, six and nine were grouped in the moderate level of recollection:

- Students who were able to define IMFs correctly, unable to give examples from class, but were able to arrange the molecules correctly and could give the correct rationale for this answer (#9) OR,
- students who were unable to define IMFs correctly, but could give examples from class and were able to arrange the molecules correctly and give the correct rationale for this answer (#6) OR,
- students who were unable to define IMFs correctly and could not give examples from class, but were able to arrange the molecules correctly and give the correct

rationale for this answer (#3). ***None of the students in this study were categorized under #3.**

Of the 39 students interviewed, only two (5%) of them were grouped in this category; one student was from CHEM 114 and the other student was from CHEM 127. Below are quotes from the students who fell under the category of moderate recollection:

> "[IMFs are] how, uh, like the molecules attract to each other…how, um, compounds come together and how they interact…H_2O would be the greatest…because it is polar…and then, the more massive, the higher the boiling point…" ~ Folake, [20, 33-34] CHEM 114 (no examples of IMFs from class – #9)

> "So intermolecular forces? So that's like between like atoms…like atoms, like being held together…there's like different types of IMFs…like London dispersion…like hydrogen bonding…so [CCl_4 and F_2] are like both non-polar and H_2O is polar…the more polar it is, the higher the boiling point… [F_2 is less than CCl_4] because] I just figured since like there's 4 chlorines, it should weigh the most, or weigh more than [fluorine]…usually if it weighs more, then it has a higher boiling point." ~ Phoebe, [18, 21, 23, 26, 28, 31, 35-36] CHEM 127 (incorrect definition of IMFs – #6)

Minimal level of recollection (#4, #5, #7, #8, #10 and #11)

Students in categories four, five, seven, eight, ten and eleven were grouped into the minimal level of recollection:

- Students who were able to define IMFs correctly and could give examples from class, but could not correctly arrange the molecules in order of increasing boiling point (#10) OR,

- students who were able to define IMFs correctly, give examples from class, arrange the molecules correctly, but could not provide the correct rationale for this answer (#11) OR,
- students who were able to define IMFs correctly, but could not give examples from class, and could not correctly arrange the molecules in order of increasing boiling point (#7) OR,
- students who were able to define IMFs correctly, but could not give examples from class, and could arrange the molecules correctly, but not provide the correct rationale for this answer (#8) OR,
- students who were not able to define IMFs correctly, could give examples from class, but could not correctly arrange the molecules in order of increasing boiling point (#4) OR
- students who were not able to define IMFs correctly, could give examples from class and arrange the molecules correctly, but could not provide the correct rationale for this answer (#5).

Of the 39 students interviewed, 22 (56%) of them were grouped under this category. Eight of the 22 students were from CHEM 114, five of them were from CHEM 127, and nine of them were from CHEM 326.

Below are some quotes from students who fell under the category of minimal recollection:

> "… [IMFs] is the force in which two molecules interact I believe…all of them are obviously somewhat stable, H_2O is [lowest] because I know [its boiling point] is pretty low, otherwise we'd be using it more often in chemistry…fluorine would more readily react than chlorine because it is higher on the [periodic table] …it

would react more, so it would take more to increase the boiling point …" ~ Eniola, [22, 34-35] CHEM 114 (no examples from class – #7)

"[IMFs] is the attraction between particles…mostly molecules…I think water would be the lowest because its boiling point seems fairly low…and then CCl_4, because it…uh, just seems like it, and then the F_2 because it's just bigger and two of the same…" ~ Esther, [27-28, 39, 41] CHEM 127 (no examples from class – #7)

"… [IMFs] is how atoms like interact with each other…I guess water, it is every day and you use it and it is hydrogen bonding… [F_2 has the highest b. p.] because it's stable…the more stable [a molecule is], the higher the boiling point…because the molecular forces are holding it tighter together, and so it won't change states as easy…water only has a boiling point of 100…it only has hydrogen bonding acting on it, and it can react somewhat easily with things, so can CCl_4… I don't know…" ~Djokovic, [21, 26, 31-36] CHEM 326 (#10)

The main difference between students that were grouped under the moderate level of recollection and those that were grouped under the minimal level of recollection was their ability to provide an accurate reason for correctly arranging the three molecules given in order of increasing boiling point. Students that were grouped under the moderate level of recollection provided a correct rationale, while students under the minimal level of recollection were unable to provide a correct rationale.

No recollection (#1 and #2)

Students in category one and two were grouped into the no recollection category:

- Students who were unable to define IMFs correctly and could not give examples of IMFs from class, were able to arrange the molecules in order of increasing boiling point, but unable to provide the correct rationale for the answer (#2) OR,

- Students who were unable to do the following: define IMFs correctly, give examples from class, and correctly arrange the molecules given in order of increasing boiling point (#1).

Of the 39 students interviewed, six (15%) of them were grouped under the no recollection category. Of the six students, four of them were from CHEM 114, one from CHEM 127, and one from CHEM 326. The following quotes are from students who fell under the category of no recollection:

> "… I know water boils relatively at a low temperature, compared to other things, so I would probably say that's the lowest… I don't know, I'm just guessing…" Tinuke, [77-79] CHEM 114 (transfer student, no definition, no examples – #1)
>
> "Uh, I have no idea [how to define IMFs]… I remember the word, I don't really remember anything from last semester…water, and then the one with Cl, and then the one with F… I don't know…" ~ Naomi, [20, 29-30] CHEM 127 (no examples from class – #1)
>
> "…[IMFs are] like the inter-workings between atoms…their relationship between each other…I just remember looking at the periodic table and um, the top right corner, or no, is it across the row the boiling point increases?... man, I'm just not recalling it, to be honest…" ~ Fernando, [13, 22] CHEM 326 (no examples from class – 1#).

Summary of levels of recollection

Figure 4.8 shows the breakdown by class of the levels of recollection of the interview participants. The majority of the 39 students who participated were able to recollect something about IMFs (33 (85%) of the 39 students). Most of these students were grouped under the minimal level of recollection (22 (56%) of the 39 students).

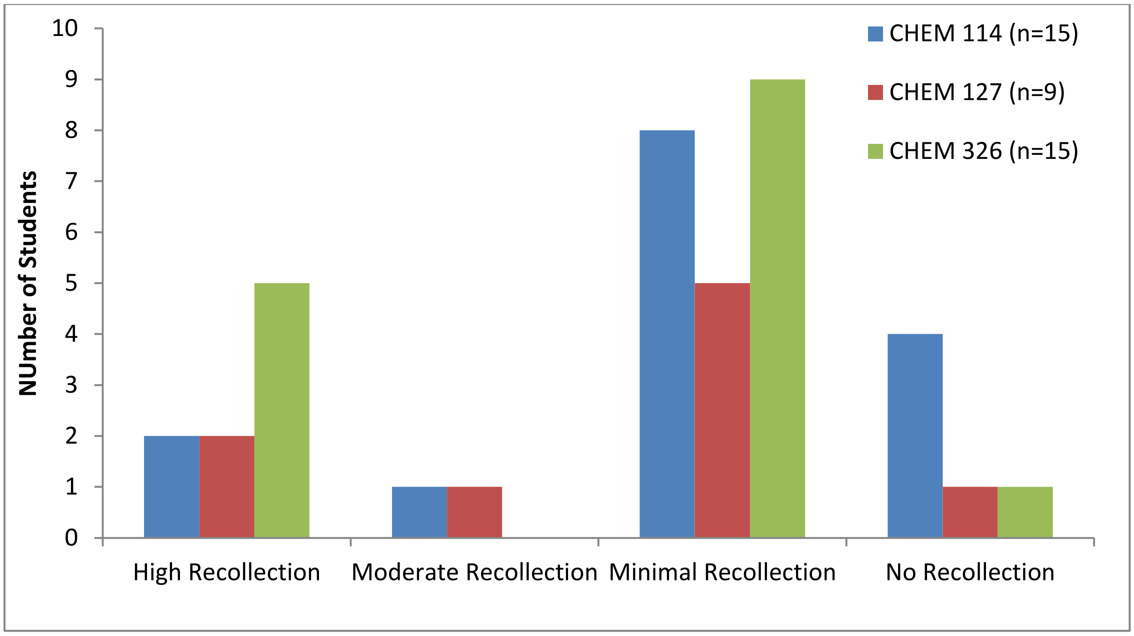


Figure 4.8. Levels of recollection according to class.

In summary, most of these students are able to recall something about IMFs, but in general, CHEM 326 students seem to remember more than both CHEM 114 and CHEM 127 students, and CHEM 127 students seem to remember more than the CHEM 114 students.

How are students able to transfer recalled knowledge?

When I first started this study, I was only interested in investigating students' abilities to transfer knowledge from their chemistry class to their daily lives, and so the question I asked during my first round of data collection was:

"Can you give an example of IMFs outside class – in your daily life? Explain." However, as I continued collecting data with the first set of students (CHEM 114 students) I realized a majority of these students were unable to provide examples of IMFs in their daily lives. In light of this observation, I decided to add another question to the interview protocol, to investigate the ability of these students to transfer knowledge from their chemistry class to other classes outside of chemistry. To address this, the following question was asked,

> “Can you give an example of IMFs outside your current class – in other classes outside of chemistry? Explain”

The full interview protocol can be found in Appendix F.

Knowledge transfer of IMFs to students’ daily lives

To answer this question, the participants were asked the following question:

- “Can you give an example of IMFs outside class – in your daily life? Explain.”

In order to categorize the students’ responses, a decision tree was again used. Figure 4.9 shows the decision tree that was used to determine students’ levels of transfer. Using this decision tree, student responses were sorted into the following categories:

- High level of transfer – category 5 in Figure 4.9
- Moderate level of transfer – category 4
- Minimal level of transfer – category 3
- No apparent transfer – categories 1 and 2

In order to ensure the reliability of this decision tree, I sought the help of a chemistry professor who had taught the topic of IMFs for over a decade – an expert in this field. Using the inter-coder reliability method, [127] I sorted all 39 participants into the four different categories and asked the professor to use the same decision tree and sort the same participants into the four different categories. The reliability coefficient between coders was 0.86 out of 1. For a qualitative study, this number is acceptable and provides credibility to the results I will be discussing.[124]

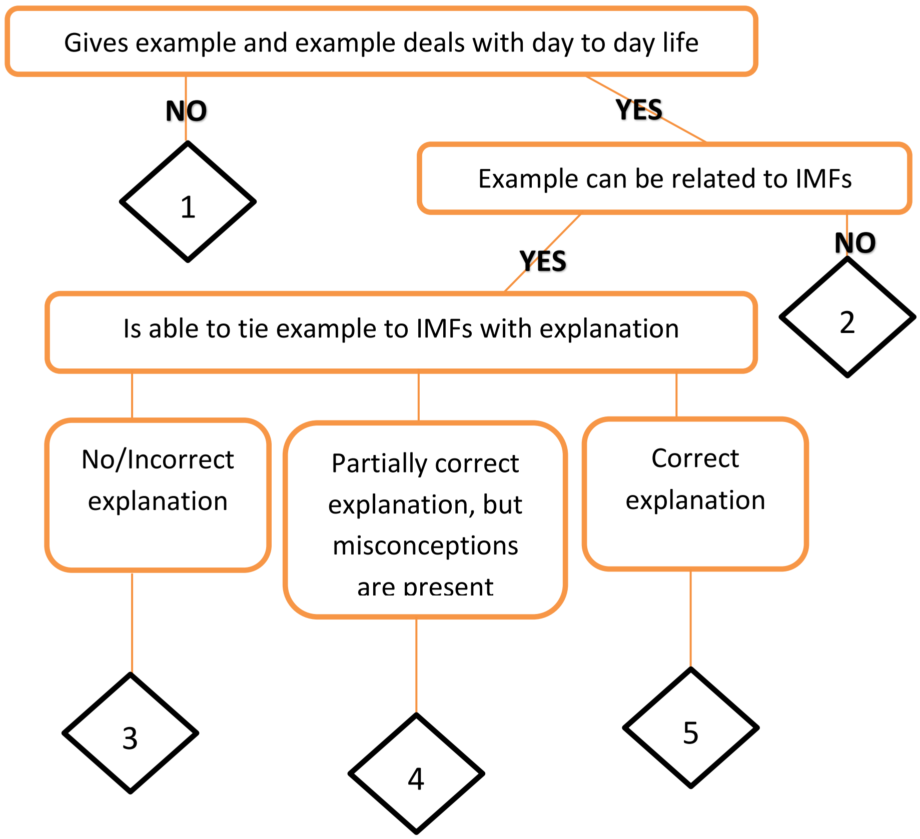


Figure 4.9. Knowledge transfer to daily life decision tree.

High level of transfer (#5)

Students who were classified in category five – high level of transfer, were able to give examples of IMFs from their daily lives and were correctly able to explain how the example given relates to IMFs. Of the 39 student participants, only five (13%) were categorized as exhibiting high transfer levels– one student from CHEM 114, three students from CHEM 127 and one student from CHEM 326. Table 4.1 shows quotes of students in category 5.

Table 4.1. Quotes from students classified under high level of transfer (category 5).

Name/Class	Quote
Sewa/CHEM 114	"[An example of IMFs outside of class, in my daily life would be] like ice melting maybe, or like water boiling, because that changes how attracted, temperature affects how molecules are attracted to each other, and how tightly the bonds are and how strong the forces are that keeps them together…as things heat up, intermolecular forces are going to get weaker…" [40-41]*
Mordecai/CHEM 127	"[An example of IMFs outside of class, in my daily life would be] water beading up…if there were no IMFs, it would just disperse, and since there are, I see water droplet…at the gas station, when you um, put your gas nozzle in and when you take it out, if there's drops left and it drips on the paint of your car, it evaporates immediately…gasoline is non-polar, there's no hydrogen bonds, I mean, there's no large IMFs to speak off…so you see it, I mean, like even when it's cold out, you see it evaporate off…" [38-44]
Caleb/CHEM 127	"[An example of IMFs outside of class, in my daily life would be] I guess whenever you take a shower and you see the water droplets either coming together or sticking um, on the uh, walls of the shower, it's the cohesive and adhesive forces…the hydrogen bonding in water, it explains all of its properties…cohesive and adhesive properties…" [23, 32]
Rafael/CHEM 326	" [An example of IMFs in my daily life would be]…well, gasoline boils, you know, really easily…has a really low boiling point because it only has van der Waal's forces, so when you, you know, are putting gas into the car, you see it coming out, just because the temperature at which it boils is very low…the energy required to break the bond between the [molecules of gasoline] is very low, so you don't have to add much heat to it." [32-33]
Priscilla/CHEM 127**	"[An example of IMFs outside of class, in my daily life would be] um, water? Boiling water…you'd have to break the like bonds or whatever…if you wanted to heat up, like a thing of water to cook some macaroni and cheese or something, you'd just have to break them…the intermolecular bonds as opposed to the intramolecular ones…" [35-37]

**Just to clarify her response, I asked Priscilla the question "So, breaking the intermolecular bonds? What would that look like?" In order to answer that question, Priscilla drew two water molecules, indicated the hydrogen bonding between the molecules with a dashed line from the oxygen atom of one molecule to a hydrogen atom of the other molecule, and indicated that the dashed line is where the 'breaking' will happen. Figure 4.10 shows Priscilla's drawing.

* The statement number based on the interview transcripts

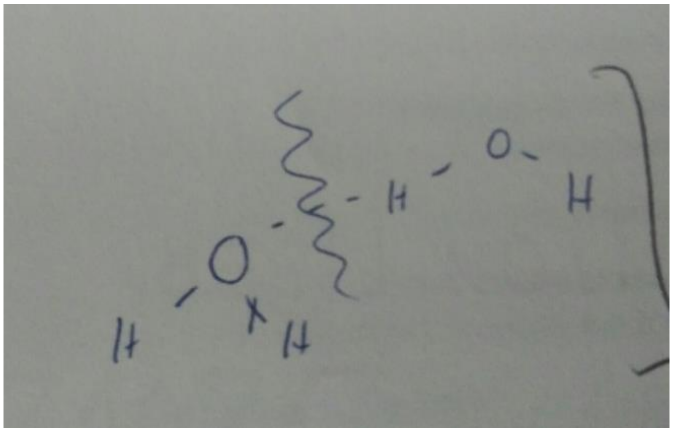


Figure 4.10. Priscilla's drawing of how hydrogen bonds break in the process of boiling

All five students who were classified under the high level of transfer to daily life, were able to give an example of something they interact with in their day to day lives (water and gasoline boiling), and were able to correctly explain how IMFs play a role in the examples they gave

Moderate level of transfer (#4)

Students in category four, moderate transfer level, were also able to give examples of IMFs that related to their daily lives, but these students were only able to give partially correct explanations of how the examples relate to IMFs, and several misconceptions were present in these students' responses. Of the 39 students that participated in the interviews, 10 (26%) of them were classified under this category – six from CHEM 114, one from CHEM 127 and three from CHEM 326. Table 4.2 shows quotes of students who were categorized under the moderate level of transfer.

Table 4.2. Quotes from students categorized under moderate level of transfer.

Name/Class	
Deji/ CHEM 114	"…salt on icy roads…the ion-dipole between the water molecules and the salt molecules decreases the melting point…the freezing point of the ice." [54-55]
Lara/CHEM 114	"Uh, let's see, intermolecular forces in everyday life… I guess like water, with like going from like solid to liquid, to gas, especially like now, when it's cold outside…you know, is it going to be like icy out, is that water?... I mean like when you add salt to water, it can like lower, it lowers the freezing point of water…salt interacts with the molecules of the water…" [25-27]
Folake/CHEM 114*	"Um, like water…when it's in a glass and it comes up on the sides a little bit, I think that's intermolecular forces…like how they, how water goes together, they're adhesive I think, or cohesive and so then they adhere to the sides of the glass…" [39-40]
Eve/CHEM 127	"Well, like I know if I boil water, that that has to break IMFs, but I don't really think about it… I'm not like boiling water and like, 'ohhh, bonds are breaking' " [37-38]
Lleyton/CHEM 326	"I mean raindrops, I mean water…if there was no intermolecular force there, then the rain drops wouldn't form, they'd just be hydrogen and oxygen floating around in the atmosphere." [41, 43]
Angelique/CHEM 326	"… I guess I always kinda like go back to baking and cooking…depending on the force…going back to boiling points, like if you're making something and you have to like, bring it up to boiling, um, that time would vary…" [33]

*Note: Folake's response is similar to that of Caleb's (in high level of transfer,) the difference though, is that Caleb talks about hydrogen bonding, while Folake does not.

All the students who were classified under the moderate transfer level were able to provide daily life examples that related to IMFs and to an extent were able to provide explanations to back up their examples. However, compared to their counterparts categorized under the high level of transfer, either they were missing a part of the explanation, or there were obvious misconceptions in their explanations. For example, Lleyton talks about atoms floating around, which would only happen if the intramolecular forces (not intermolecular forces) were broken. In the quotes from Deji and Lara, the misconception here is that IMFs cause the decrease in the freezing point of water, which is not fully correct. IMFs are involved in the interactions of the solute (salt) and the solvent (water) and are responsible for the dissolution of the solute in the solvent. However, dissolving a solute in a solvent increases the entropy (level of disorder) of the system, and consequently lowers the vapor pressure of the system. This increase in entropy, and not just IMFs, is what causes a decrease of the freezing point and an increase in the boiling point of the solution.[158] In the case of Angelique, Eve and Folake, all three participants are missing some part of the explanation.

Minimal level of transfer (#3)

Students in category three, low transfer level, were also able to give examples of IMFs from their day-to-day lives. However, these students were unable to explain how IMFs play a role in the examples they gave. The students in this category either gave an incorrect explanation, or were unable to give an explanation when asked for one. Of the 39 participants, 14 (36%) of them were categorized under low level of transfer– six of the 14 students were from CHEM 114, one from CHEM 127, and the remaining seven were from CHEM 326. Table 4.3 shows quotes from some students that fell under this category.

Students who were classified under category three were able to provide an example that related to their day-to-day lives, and that could potentially be directly related to IMFs. However, these students were unable to give either a correct or a partially correct explanation to relate their examples to IMFs.

Table 4.3. Quotes from students categorized under low level of transfer (category 3).

Name/Class	
Tutu/CHEM 114	"…when you open the pop, it makes that noise of the gas releasing…when you hear it fizz, obviously there is a chemical combustion going on, so that's like an intermolecular force in there…" [34, 44]
Tunde/CHEM 114	"Um… I guess wouldn't water be an example...just because of the way like hydrogen um, is H^+ and oxygen is O^{2-} , like that affinity causes then to react and um, basically then they form water… I don't know, that also affects like the different phases of water, like solid, liquid, gas…I don't remember…" [30-32]
Tinuke/CHEM 114	"… I guess for me what I can think of is like in a job as a pharmacist, like how medicine works and the way it reacts, I guess…like medicine is made up of chemical substances and it works because um, of how it reacts, I guess I don't really know…" [38-39]
Phoebe/CHEM 127	"Um…like in medicines, the compounds are like held together by certain ones, so if you have like aspirin or something, it's held together by covalent bonds." [40]
Tsonga/CHEM 326	"Um, wouldn't that be like with water technically…You drink it…" [40-41]
Djokovic/CHEM 326	"… I don't know, with like adhesion of stuff and…hmmm, uh, yeah…like different glues, I guess the molecular forces will bond better with some materials than others…" [39, 44]
Venus/CHEM 326	"…um, in my daily life…what made me think of just like chemistry in my daily life would just be like the simple process of like boiling water in some sort of way…just knowing that the bonds are breaking and that's what's causing the boiling of the water, and then like the hydrogen…is it hydrogen gas that like evaporates?" [30]

No apparent transfer (#1 and #2)

The students in categories one and two, no apparent transfer (Figure 4.9), were either unable to give examples from their day-to-day lives (#1), or gave examples from their day-to-day lives that did not relate directly to IMFs (#2). No participant in this study was categorized under #2. Ten of the 39 student participants were unable to give an example of IMFs from their daily lives (#1). Four of the 10 students were CHEM 127 students; four were CHEM 326 students, while the remaining two students were from

CHEM 114. Table 4.4 shows quotes from students that were categorized under the no apparent transfer category.

Table 4.4. Quotes from students categorized under low level of transfer (categories 1 and 2).

Name/Class	
Abike/CHEM 114	"…I know, pretty sure we used some in lab, but I can't remember…"[47] (#1)
Keturah/CHEM 127	"I'm not exactly sure how [IMFs] work…" [37] (#1)
Zipporah/CHEM 127	"…uh, not really [I can't really give an example from my daily life], like I feel like when we talked about it in class, you know, like you're taught, like, this is what it looks like, this is the structure and like they tell you kind of like the answers that will be like on a test, but like we don't really talk about like how it surrounds you that much everyday…" [36] (#1)
Agnieszka/CHEM 326	"[An example] like in day to day life...no, [I can't give any], not dealing with like specific chemicals or anything…" [32-33] (#1)
Dominika/CHEM 326	"… I mean, I can't really give a specific [example]… I know that um, molecules, like organic chemistry, they're in everyday products, but I couldn't tell you which products have like certain, like, molecules… I couldn't tell you that…" [48] (#1)

Summary of levels of transfer from class to daily life

Figure 4.11 gives a summary of the levels of transfer for the 39 student participants. Most of the 39 students who participated were able to transfer something about IMFs to their daily lives. Only 10 (26%) of the 39 students were categorized under the no apparent transfer level.

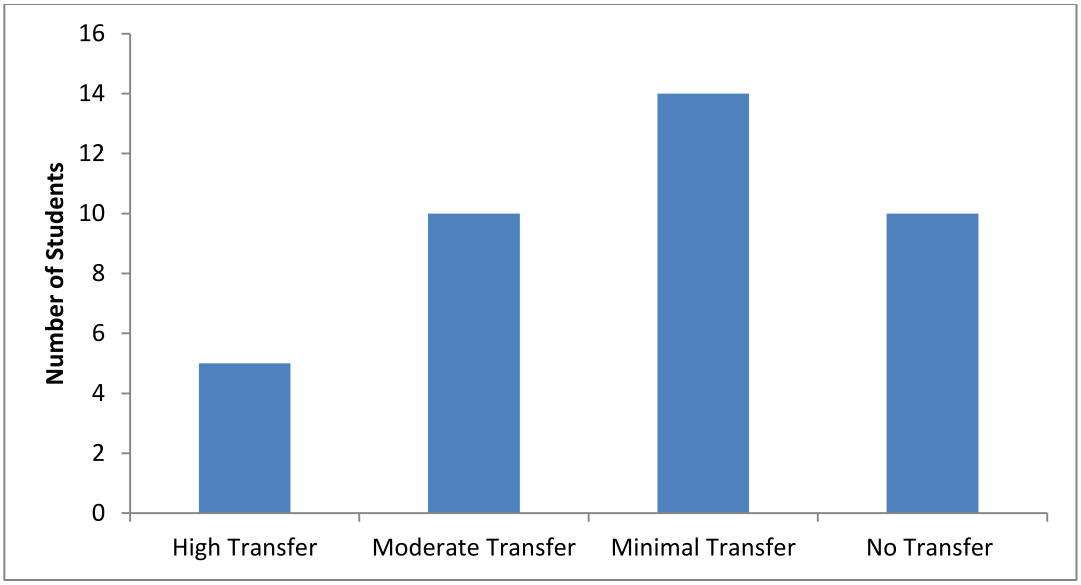


Figure 4.11. Levels of transfer to daily life for the 39 student participants.

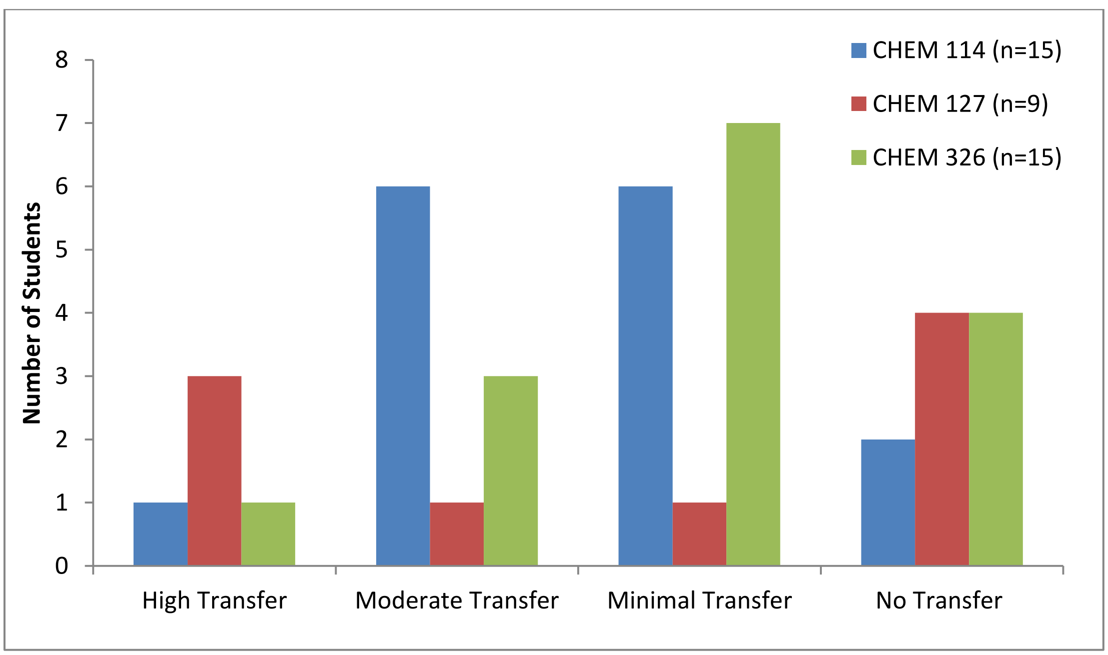


Figure 4.12. Levels of transfer to daily life for CHEM 114, CHEM 127 and CHEM 326.

Figure 4.12 gives a breakdown of the levels of transfer to daily life by class, and shows that most of the students in CHEM 114 were classified under the moderate and low levels of transfer. Of the 15 total participants in CHEM 114, six (40% of 15) of them had moderate levels of transfer, while another six (40% of 15) had low levels of transfer. The trend observed in CHEM 127 is almost an ‘all or nothing’ trend; as shown in Figure 4.12, most of the students in this class either have a high transfer ability (three (33%) of the nine total participants) or have no transfer ability at all (four (44%) of the nine participants). The trend seen in CHEM 326 (Figure 4.12) is that most of the students were classified under the low and no transfer levels. Seven (47%) of the 15 total participants in CHEM 326 had low levels of transfer, while four (27%) of the fifteen had no transfer at all.

These trends are interesting and could be because of certain factors. The trends observed in CHEM 114 and CHEM 326 could be due to the emphasis placed (or not placed) on transfer to daily life by the professor. The roles professors play in transfer will be discussed later on in this chapter. The trend observed in CHEM 127 could be because of the different chemistry backgrounds of the students since the students that take this course are either honors students or chemistry/biochemistry majors. The different high school chemistry backgrounds and the different emphases high school teachers place on transfer to day-to-day life could also play a role in the trends observed in CHEM 127. As this study does not specifically address the reasons behind these trends, this is pure speculation on my part. These trends will be discussed in more depth in CHAPTER 5 (Cross Analysis).

Knowledge transfer of IMFs to other classes outside of chemistry

In order to address this question, the following question was asked:

> "Can you give an example of IMFs outside class – in other classes outside of your chemistry class? Explain."

I only asked CHEM 127 and CHEM 326 students this question because I had finished collecting the interview data for the CHEM 114 students when I decided to put the question into the interview protocol. I made this decision when I realized several of the CHEM 114 students I interviewed were struggling with transferring the concept of IMFs to their daily lives.

Students' responses were categorized with the help of a decision tree, shown in Figure 4.13. Using the decision tree, the interview responses were organized into the following categories:

- High level of transfer – category 6 in Figure 4.13
- Moderate level of transfer – category 5
- Minimal level of transfer – category 4
- No apparent transfer – category 1, 2 and 3.

High level of transfer (#6)

The students in category six, high transfer level, were able to identify a class outside of chemistry where IMFs can be seen, give an example relating to IMFs from the class and correctly explain how the example given relates back to IMFs. Of the 24 CHEM 127 and CHEM 326 students that were interviewed, only three (13%) were classified under the high transfer level – one student from CHEM 127 and two students from CHEM 326.

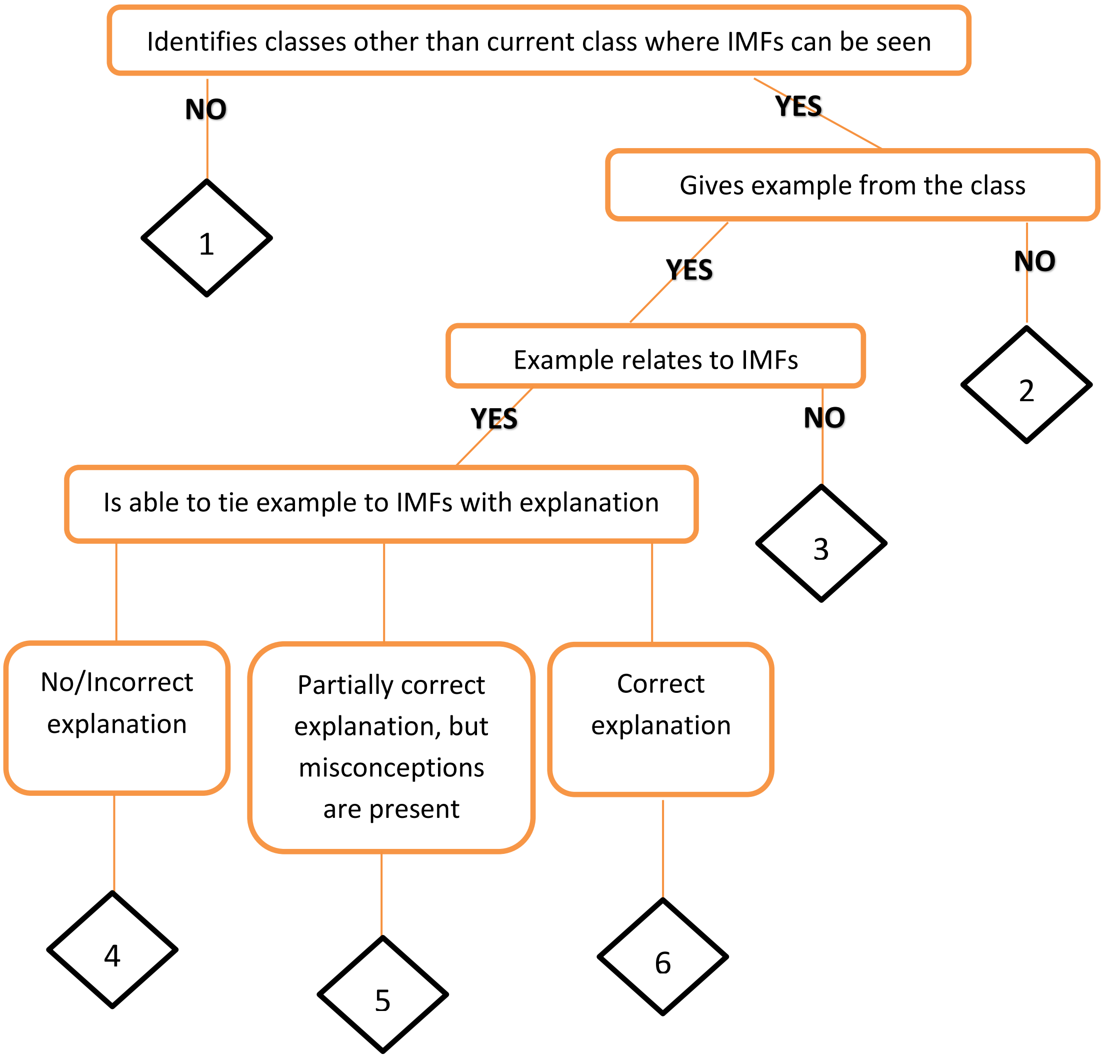


Figure 4.13. Decision tree for knowledge transfer to other classes.

The following quotes are from the three students classified under high levels of recollection:

> "Uh, biology…like xylem in plants…the wall of plants, uh, veins, I think they're called veins, something like that, but anyway, because water has those hydrogen

> bonds, it's able to cling to the sides, and you know, climb up to be used for photosynthesis…" ~ Mordecai, [44] CHEM 127
>
> "… I see IMFs' role particularly in BIOL 202 [genetics and cellular biology] when examining a molecule's partition coefficient, its ability to exist in a hydrophobic and hydrophilic environment. Molecules must be able to diffuse through both types of environment in order to enter a cell… although this is not completely dependent on IMFs, size also plays a role, understanding the types of IMFs are necessary to predict the movement potential for a molecule." ~ Rafael, [61] CHEM 326
>
> "Um…last spring in my biology class, uh, I remember hearing something about how geckos can like climb on walls and stuff by, I think it was through like using van der Waal's [forces] like very temporary interactions between the surface, and so that was really kind of cool." ~ Gael, [36] CHEM 326

These three students were able to identify a class outside of chemistry where IMFs could be applied, and were also able to give an example from that class and talk about how the knowledge of IMFs impacts the example they gave.

Moderate level of transfer (#5)

Students in category five, moderate transfer level, were also able to identify a class outside of chemistry where IMFs can be seen and give an example relating to IMFs from the class. However, the explanations of these students were partially correct and/or contained certain misconceptions. Of the 24 students that were asked this question, only one student (Angelique) fell under this category. The following quote is from Angelique, a CHEM 326 student:

> "Um, we've actually learned about [IMFs] in my physiology class, so that has been kind of interesting, and like kinda linking that together…like with the different kinds of proteins, there's uh, like primary, secondary, tertiary and quaternary…so like the bond or the intermolecular forces change based on that, so I believe the primary is hydrogen [bonding], the secondary is dipole, either that or the other way around, but um, so just like the strength [of the IMFs relates to] like the ability for your body to break down those proteins too…like your body has difficulty breaking down like beta bonds more than alpha bonds, and so that's why, um, like, some people like have difficulty breaking down lactose…" ~ Angelique, [36-38] CHEM 326

Angelique does recognize that IMFs play a role in how proteins are linked together, but then begins to talk about the body breaking alpha and beta bonds, which are examples of intramolecular bonds, and not intermolecular forces. Even though she is able to see IMFs in her physiology class, she still has certain misconceptions about IMFs and the roles they play in the body.

Minimal level of transfer (#4)

Students in category four, minimal transfer level, were able to identify a class outside of chemistry where IMFs could be seen, give examples from that class that related to IMFs, however, these students were unable to explain how the example given tied back to IMFs. Of the 24 students, four (17%) of them were categorized under the low transfer level. Two of the students were from CHEM 127 and the other two from CHEM 326. Table 4.5 shows quotes from the students who had low levels of transfer.

Table 4.5. Quotes from students that were categorized under low transfer levels (category 4).

Name/Class	
Phoebe/CHEM 127	"…we've talked about [IMFs] quite a bit in biology…we talked a lot about like adhesion and cohesion with water, but then like with like lipids, um, and I don't know, pretty much like any of the carbohydrates…" [41-42]
Caleb/CHEM 127	"…I think we talked about [IMFs] in biology, um, we talked about all the properties that water had as like a solvent, cohesive/adhesive forces, high specific heat, high heat of vaporization… I don't actually think we ever used it, except for the high specific heat as a solvent, but really biology didn't delve in it, but mentioned it…" [35]
Djokovic/CHEM 326	"… I guess in like biology, like it's every now and then, but it's not like… it's just kind of, like word-dropping, it's not like necessarily going into the topic…we talked about with blood and how blood bonds and how like different blood types interact with each other…" [40-41]
Simona/CHEM 326	"…we've talked about [IMFs] somewhat in like microbiology and then physiology…we talked about it a lot in microbiology when we did diffusion and osmosis and how things move, and then in phys, we talked about it somewhat with like stuff in the blood and nutrients and stuff…mostly [the professors] just said it…" [29-31]

All four students, Phoebe, Caleb, Djokovic and Simona, were able to provide examples that were discussed in their various classes (mostly biology classes), but were unable to expound on any of the examples given. They all remembered the ideas/concepts that were talked about in relation to IMFs in their classes outside of chemistry, but were not able to explain how these ideas tied back to IMFs.

No apparent transfer (#1, #2 and #3)

Students in categories one, two and three, no apparent transfer level, were placed there because:

- Students who were unable to identify a class outside of chemistry where IMFs could be used (#1)
- Students who were able to identify the class, but unable to give examples from the class (#2)

- Students who were able to identify a class, and give examples, but did not give examples that related to IMFs. (#3)

Sixteen (67%) of the 24 student that participated in this portion of the interview were classified under the no apparent transfer level. Two-thirds of students from both CHEM 127 (n = 6) and CHEM 326 (n = 10) were unable to transfer information from their chemistry class to classes outside of chemistry. This implies that most of the students in CHEM 127 and CHEM 326 could not connect information learnt about IMFs in their chemistry classes to classes outside of chemistry. Table 4.6 shows quotes from students who were categorized under the no apparent transfer level.

Table 4.6. Quotes from students categorized under the no apparent transfer level (categories 1, 2, and 3).

Name/Class	
Priscilla/CHEM 127	"…ok, so there's the BIO 151 that I used it, and I think that's about it." [34] (#2)
Eve/CHEM 127	"No [I haven't seen IMFs in other classes], other than just chemistry…" [36] (#1)
Venus/CHEM 326	"Uh, not much actually [I haven't seen much of IMFs in other classes]. I feel like that's a lot more of just chemistry. Um, I know in anatomy just last week, we were talking about just like a chemical reaction when you breathe, which was nice to see that the biology and chemistry was coming together, at least just a little bit there. But I haven't seen much of IMFs in other classes come together." [33] (#1)
Serena/CHEM 326	"…um, let's see, in genetics and microbiology, we're talking a lot about the electron transport chain and so, how willing, um, something is able to give up the electrons will, um, if it's a good acceptor for the end of the chain, or if it's going to donate, um, will give you different amounts of energy…because if something is, I feel like electronegative is not the right word, but if it's willing to give up the electrons, that's a force in it…that's probably more intramolecular, isn't it?... I guess I can't think of any examples off the top of my head…" [47-50] (#3)
Tsonga/CHEM 326	"Um, I think we see [IMFs] a lot in biology, um, just because we're looking at a lot of stuff that are at the molecular level, so I think it gets introduced a lot there, I just like, forget how…I think ATP synthase probably has a little bit to do with it, like the TCA cycle. Like it might not be talked about, but I think it happens in there…" [31] (#3)

Like most of the students that were categorized under this no transfer category, Eve and Venus do not see IMFs relating to classes outside their chemistry classes. Priscilla was able to identify a class outside of chemistry that could involve IMFs, but was unable to give any examples from that class.

Other students in this category had responses similar to those of Serena and Tsonga. These students were able to identify classes outside of chemistry where IMFs could be seen. However, when it came to examples, they gave examples that did not relate to IMFs. Serena talked about the electron transport chain, while Tsonga talked about the citric acid cycle, both of which deal primarily with what is happening to molecules on the intramolecular level. The electron transport chain and the citric acid cycle do not have obvious applications of IMFs, and these students were unable to explain how and why they believed IMFs were involved in these processes.

Summary of levels of transfer from chemistry class to other classes

Figure 4.14 shows a breakdown by class of the levels of transfer of the knowledge of IMFs from the chemistry class to classes outside of chemistry. Two-thirds of the CHEM 127 (six of nine) and CHEM 326 (10 of 15) student participants were unable to transfer knowledge about IMFs to classes outside of chemistry. This is something that should be considered because most of the students that participated in this study stated that they were motivated to learn chemistry because it related to their major.

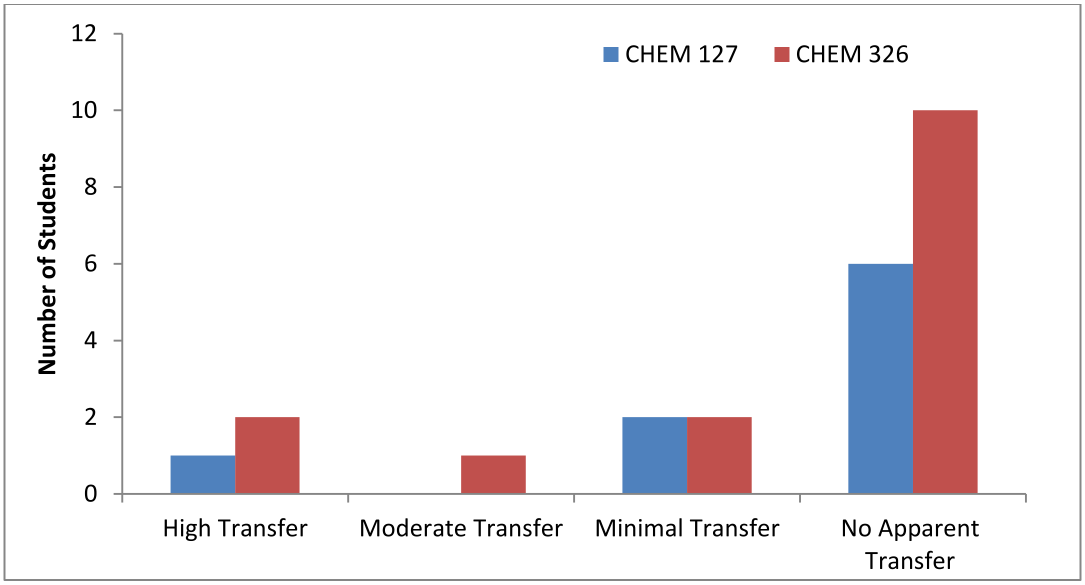


Figure 4.14. Levels of transfer to other classes broken down by class (CHEM 127 and CHEM 326).

How do additional classes influence knowledge transfer of IMFs to daily life?

The concept of IMFs was first introduced either in CHEM 112 – the first semester of general chemistry for science/pre-professional majors (taken by CHEM 114 and CHEM 326 students) or CHEM 115 – the first semester of chemistry for honors/chemistry majors (taken by CHEM 127 students). The student participants in both CHEM 114 and CHEM 127 typically would have only taken one other college level chemistry course at this university (CHEM 112 and CHEM 115 respectively). The student participants in CHEM 326 typically would have taken at least the CHEM 112 and CHEM 114 series. Due to this difference in the number of chemistry courses taken by CHEM 326 students and CHEM 114 & CHEM 127 students, I explored the influence of an additional chemistry classes on students' abilities to transfer knowledge of IMFs to their everyday lives.

In order to investigate this, the following questions were asked:

- Have you learnt anything new about IMFs in your present class? (If the student gave a positive answer to this question, then the following questions were asked)
    - Can you please provide an example?
    - Did what you learn help improve your understanding of IMFs? How?
    - [Based on the response to the question above] Has your understanding of the application of IMFs to your everyday life changed? How?

The student responses to the first question were initially categorized as three distinct types:

- No, I have not learnt anything new
- No, I have not learnt anything new, but… (student talks about where IMFs have come up in their current class, and/or some application of IMFs)
- Yes, I have learnt something new.

After reading through students' responses, the second and third categories were combined because students that indicated they had learnt something new were basically building off past knowledge of IMFs, which was similar to the responses that were categorized under 'no, but...' Table 4.7 shows how students in the three classes (CHEM 114, CHEM 127 and CHEM 326) responded to the initial question.

Table 4.7. Students who learnt something new (or not) about IMFs in their current class

	No	No, but… or Yes
CHEM 114 (n=15)	9	6
CHEM 127 (n=9)	7	2
CHEM 326 (n=15)	5	10

A majority of students in CHEM 114 (nine (60%) of 15 students) and CHEM 127 (seven (78%) of nine students) stated that they had not learnt anything new about IMFs in their current class, while five (33%) of the 15 CHEM 326 students said they had not learnt anything new about IMFs in their current class. Please note that CHEM 326 students had a week of review, where the professor highlighted areas in general chemistry that he believed were important for students' success in the class. As a part of the review, he gave a brief summary of IMFs, emphasizing the main points. Table 4.8 shows quotes from students who said they had not learnt anything new in their current class:

Table 4.8. Quotes from students with no new knowledge about IMFs in current class.

Name/Class	
Tutu/CHEM 114	"… [makes negative noise and shakes head], we just learned about…what did we just learn about…ICE charts [the table used for equilibrium calculations] and all that…" [46-47]
Ola/CHEM 114	"…not yet, just a lot of equilibrium…" [67]
Eniola/CHEM 114	"…not yet, right now we're working mostly on equilibriums and acid and base and the Kas [equilibrium constants] and pKas…" [43]
Bayo/CHEM 114	"…not really…we're talking about chemical reactions…just how the rates and the rate of forward and reverse reactions of chemicals…" [51]
Zipporah/CHEM 127	"…um, no, we've pretty much just focused on naming alkenes and like chiral molecules and like how to draw stuff…maybe we'll start getting into more of it because now, we're actually starting to look at reactions…" [49, 51]
Angelique/CHEM 326	"… I don't think so…we might have gone through it, because a lot of the stuff was review…" [41]
Fabio/CHEM 326	"… I don't think so. I mean, I'm sure we probably have a little bit, but not to any great extent at all…possibly because it isn't necessary for what we're doing…maybe we'll get into it more, I don't know…" [55-56]
Fernando/CHEM 326	"…Um, not off the top of my head, I mean just in the review of the first couple of weeks, I feel like we just basically went over molecular forces, that's all I can really recall." [34]

A majority of CHEM 326 student participants (10 (67%) of 15 students) either indicated they had learnt something new about IMFs, or that they had seen some application of

IMFs in the topics they were covering in class. Six (40%) of the 15 CHEM 114 students and two (22%) of the nine CHEM 127 students reported that they had either learnt something new or seen an application of IMFs in their classes. Table 4.9 shows quotes from these students.

Table 4.9. Quotes indicating new knowledge of IMFs or applications of IMFs.

Name/Class	
Mojisola/CHEM 114	"…we're learning about Ksps [equilibrium] and strong electrolytes and if they dissolve in water, so that probably, because it's part of [IMFs], if it dissolves in water or if it doesn't, the forces in between each molecule, if it stays or it doesn't stay…" [51]
Deji/CHEM 114	"… I don't believe there's been any topic on [IMFs] really… I suppose [IMFs] kind of all applies, with like the, the dissolving of acids and stuff in like a non-aqueous solution, so [IMFs] probably does apply, but I don't remember learning about it explicitly at all…" [60]
Tunde/CHEM 114	"…we briefly touched on it in like the first chapter… I think maybe the intro to like equilibria and stuff…sometimes equilibrium can be affected by like intermolecular forces…because like, equilibrium is an application for IMFs…" [37-39, 41]
Folake/CHEM 114	"…not anything particularly new about [IMFs], but I know that they like stayed with us and they've applied to, they keep staying with us in how we do the things we do, and they are important to the chemical, um, the compounds we are using." [42]
Feyi/CHEM 114	"um… I think we mentioned [IMFs] every once in a while, but we haven't learned anything huge…" [53]
Lara/CHEM 114	"…not really… I guess we're talking about acids and bases, so I'm sure that like goes with, you know, but we haven't really talked, I don't remember him saying intermolecular forces in a long time…" [33]
Phoebe/CHEM 127	"…I don't know if we necessarily like learned new, just kind of like reviewed what we like knew before…" [56]
Eve/CHEM 127	"…um, not really, I don't think , we don't really talk about IMFs, but like how, like positive region , like something that has like a stronger bond or whatever, like may not react as well, I guess. So it's not like really talking about the forces, but like, if it doesn't, like come off as easy, then it won't react as well." [48]
Rafael/CHEM 326	"…well, certainly as far as the strength of dipoles as it related to like resonance. I hadn't realized in like general chemistry that uh, like an alkene, alkyne, CH_3 group will…through the inductive effect will donate electrons and stabilize carbocations and stuff…" [36-37]
Lleyton/CHEM 326*	"…yeah, I've learned a lot…hydrogen's the strongest, dipole-dipole, the surface area is most important on a van der Waal's…dipole-dipole relates a lot with electronegativity and the size of the molecules, as far as the bond length…basically everything I know about intermolecular forces came from this class so far…" [46-47]

Tsonga/CHEM 326	"… I think [IMFs] might have been talked about a little bit, more like, um, elimination, substitution and breaking bonds and forming them again and stuff like that…" [46]
Djokovic/CHEM 326	"…no, but I guess it's just more detailed and how they are used in chemical reactions…" [46]
Gael/CHEM 326	"… I don't know it it's necessarily new, but there's a lot of like reinforcement and um, I don't know, I guess like being constantly exposed to the same material, but like maybe a little more in-depth is kind of what's going on…" [42]
Agnieszka/CHEM 326	"…yeah, well, we've talked about how…like carbocations and like transition states, with organic molecules as they're going through like reactions, so it's not like really new, but we've learned to apply it in different ways, so there's like, again, like dipole moments in the transition states of an organic reaction…" [34]
Petra/CHEM 326	"… I think that like [professor] hasn't necessarily sat down and been like, 'let's talk about IMFs'…it was more like, 'let's build on what we already know'. So it's like, 'you should know what [IMFs] are, so now we're going to talk about how [IMFs] matter in these types of reactions, or within these molecules, and how it affects their shape… so I think like not necessarily new information, but like talking about it in different ways." [43]

*Lleyton was a transfer student; his only exposure to IMFs was the current CHEM 326 class

After these students (Table 4.9) indicated that they had learnt something in addition to what they had been taught in either CHEM 112 or CHEM 115, I asked the following additional questions:

- Can you please provide an example?
- Did what you learn help improve your understanding of IMFs? How?
- Has your understanding of the application of IMFs to your everyday life changed? How?

The responses to these questions are discussed according to each class below.

CHEM 114

To recap, of the 15 CHEM 114 participants, six (40%) of them indicated they either had learnt something new about IMFs, or had seen some application of IMFs in the topics they were covering in class. Of these six students, five of them were able to give examples of concepts that related to IMFs. The sixth student, Feyi, said, "… I think we mentioned [IMFs] every once in a while, but we haven't learned anything huge…" [53], when she was asked to give an example, she said, "… I don't know, I can't even remember anymore…"[54].

Table 4.10 shows the responses of the other five CHEM 114 students to the additional questions. These five CHEM 114 students talked about seeing IMFs in one of these two topics – acid/base chemistry or equilibrium, which are two main topics covered in CHEM 114. Of these five students, Deji, Tunde and Lara, identified topics in their current class that could be related to IMFs, but were unable to explain that relationship – they recognized that there was a relationship between IMFs and the topic they mentioned, but they did not know the relationship. On the other hand, the other two, Mojisola and Folake, attempted to explain the relationship between the topics they identified and IMFs, but had certain misconceptions present in their explanations. Both Mojisola and Folake talked about the relationship between equilibrium and IMFs, and how IMFs influence the process of dissolution. According to Folake, "… you see IMFs there [in equilibrium and acid/base chemistry] because they affect, like if something was more polar or how they connect to each other …two things come together and then they form a certain **bond**…how they split apart and come together, and then that affects how they are in equilibrium… ."[45] Mojisola's thought process was also very similar; she believed the IMFs played a role in determining how things dissolved – which is true. However, when probed further, she said, "…the forces [IMFs] **in between each molecule** [determines] if [the molecule] stays or doesn't stay [together]...because **molecular forces [IMFs] are what keeps them… the ions in a molecule…together**…" [51, 59]

Table 4.10. Responses of CHEM 114 students with new knowledge or applications of IMFs.

	Example provided	Improved understanding of IMFs?	Change in understanding of application of IMFs to daily life
Mojisola	"…we're learning about Ksps [equilibrium] and strong electrolytes and if they dissolve in water, so that probably, because it's part of [IMFs], if it dissolves in water or if it doesn't, the forces in between each molecule, if it stays or it doesn't stay…" [51]	"Yeah…like just, how strong the bonds are in between each molecule and just if it's like going to stay or not…because you have to figure out the Ksp, if it dissolves or not…molecular forces are what keeps them together." [52-53, 58-59]	"Um…not really…it's kind of stayed the same." [63-64]
Deji	"… I don't believe there's been any topic on [IMFs] really… I suppose [IMFs] kind of all applies, with like the, the dissolving of acids and stuff in like a non-aqueous solution, so [IMFs] probably does apply…we don't explicitly state what the IMFs are doing, but I believe that they're always going to have something to do with it…" [60,62]	"…honestly, personally, I just think [if I didn't] crash study or cram study, 'cause then I lose a lot of [information] in like a week or so, [it would improve my understanding of IMFs]…" [65]	"[my understanding could be changed by] I guess, just examples, like when learning about them…[professor] probably did go over some examples in class, but I just don't remember any of them…" [71]
Tunde	"…we briefly touched on it in like the first chapter… I think maybe the intro to like equilibria and stuff…sometimes equilibrium can be affected by like intermolecular forces…because like, equilibrium is an application for IMFs…" [37-39, 41]	"Um, a little bit…just because it kinda shows you like how some of the theories he talked about, like say electron affinity, electronegativity, um, how those actually like play out in a reaction…like in real chemistry…like how it kind of applies…" [42-43]	"A little bit" [50]*doesn't not explain how
Folake	"…not anything particularly new	"… I don't know if it [has improved my	"Uh, it hasn't changed how I see it in the

	about [IMFs], but I know that they like stayed with us and they've applied to, they keep staying with us in how we do the things we do, and they are important to the chemical, um, the compounds we are using…like if something was more polar, or how they connect to each other, so like…two things come together and then they form a certain bond…how they split apart and come together, and then that affects how they are in equilibrium…" [42, 45]	understanding], but I just know like, you can see the importance of [IMFs], and like how everything in chemistry connects together as a whole." [41]	real, like real world applications, but, like again, it just makes it more relevant, 'cause you can connect it to more things 'cause you know it affects what you are doing now, which affects other things, and you just see how everything is connected." [50]
Lara	"…not really… I guess we're talking about acids and bases, so I'm sure that like goes with, you know, but we haven't really talked, I don't remember him saying intermolecular forces in a long time…" [33]	"So far, I guess now that I actually think about what we're actually doing, yes, [it has helped me improve my understanding of IMFs] … I guess it's kind of interesting to like build on the knowledge of 112 too… I wish [professor] would refer back to 112…" [43]	"Um, I think [my understanding of the application to daily life has improved] …not as much as I should be taking out of it to real life…especially doing the backgrounds in the lab reports…you have to scramble and find real world examples, and you're coming up with things and you're like, 'oh yeah', because chemistry is kinda like the basis of everything." [45]

The main issue with Folake and Mojisola's thought processes is that they confuse intermolecular forces, the forces between different molecules, and intramolecular forces, forces that keep one molecule together. Even though these five students in CHEM 114 were able to provide topics from their current class that related to IMFs, they were unable to link these topics to IMFs correctly. However, even with their inability to explain correctly the relationship between IMFs and the topics of acid/base and equilibrium, when probed, these students were beginning to recognize that topics in chemistry are connected and build off each other.

When these five CHEM 114 students were asked if their understanding of the application of IMFs to their daily lives had changed, they reported little to no change. Tunde, Lara and Deji reported minimal changes to their levels of understanding, but were unable to provide specific examples. Mojisola and Folake reported no changes to their understanding of the application of IMFs to their daily lives.

CHEM 127

Of the nine CHEM 127 participants, two (22%) of them, Eve and Phoebe, indicated they had either learnt something new about IMFs, or had seen some application of IMFs in the topics they were covering in class. Table 4.11 shows the responses of Eve and Phoebe to the additional questions.

Eve talked about the relationship between IMFs and acid/base chemistry. Similar to students in CHEM 114, Eve also confuses intramolecular forces with intermolecular forces. According to her,

> "…like something that has like a stronger bond or whatever, like may not react as well…it's not like really talking about the forces [IMFs], but like, if it [the atom] doesn't, like come off as easy, then it won't react as well." [48]

When Eve was asked specifically what she was talking about, she said,

> "Um, today we kind of like, when we were talking about acids and bases, like how it donates or accepts a hydrogen, and like, if you have like a molecule that has like a Cl [chlorine atom] bonded to it, like that's not going to, like that's going to pull electrons towards it and it's not going to want to accept [a hydrogen] as much…" [50]

Eve was specifically referring to acid/base chemistry in statements 48 and 50, and even though there are IMFs involved in acid/base chemistry, her explanation was looking more at the intramolecular forces keeping an atom bonded (or not) to the molecule, as opposed to the intermolecular interactions of the molecule with another molecule or ion.

Again, like her counterparts in CHEM 114, Eve was able to identify a topic in her class that related to IMFs, but unable to describe correctly the relationship between the two topics. Phoebe on the other hand talked about hybridization and bonding, specifically bond length, as examples that related to IMFs. According to Phoebe,

> "…we talked about the bonding and like hybridization…about like the different orbitals and like how they mix when there's a bond…so if you had like a carbon, like CH_4, there's not going to be like one bond that is longer…they hybridize so that they can be relatively equal in length…if it's the same atoms surrounding the central atom, then there's not going to be one bond that's like stronger…they should all be relatively the same, have relatively the same strength." [57-58,60]

Hybridization deals primarily with intramolecular forces, while bond length is indeed related to IMFs. However, Phoebe's explanation focuses on the intramolecular forces that keep the hydrogen atoms bonded to the central carbon atom and the fact that the same atoms have the same hybridization, which should result in the same bond length. Phoebe's example and explanation further highlights the confusion students have between intermolecular forces and intramolecular forces.

Table 4.11. Responses of CHEM 127 students with new knowledge or applications of IMFs

	Example provided	Improved understanding of IMFs?	Change in understanding of application of IMFs to daily life
Eve	"…um, not really [learnt anything new], I don't think, we don't talk about IMFs, but like how, like the positive region, like something that has like a stronger bond or whatever, like may not react as well…so it's not like really talking about the forces, but like if it [the molecules] doesn't like [break apart] as easy, then it won't react as well…" [48] (specifically talking about acid/base chemistry)	"… I feel like it does help [my understanding], just like applying it and not having to think about it is nice because, like, you understand more, I feel, if you see it constantly, so like, it's not explained that, 'oh, these are IMFs' , but we all know, and then you just pay attention to what kind of bonds are happening." [52]	"…um, yeah, I feel like you don't pick up on [daily life applications] as much, but when you talk about like more acid and bases, and with those, you can see more of those kind of like everyday reactions kind of thing with acids and bases, so then that kind of makes me think about IMFs…" [53]
Phoebe	"…Um, so in organic chem, we, I don't know if we necessarily like learned new, just kind of like reviewed what we like knew before…so we talked about the bonding and like hybridization more…we hit on that more than we did before in previous courses…" [56-57]	"I think [it has helped me improve my understanding], because before you just kind of like hear about the bonds, and you don't really like think anything about it, but then when you learn like that they can hybridize, and then they're now like equal, I don't know, it helps me understand it better, I guess." [61]	"Um, I suppose it has… I think so because he gives us examples like, of the different, like, well maybe not in my daily life, but like, like real life applications, like how the medicine…like looking at those structures, then you can more clearly visualize the bonds if you know the hybridization…" [62-63]

Both Eve and Phoebe reported that their understandings of IMFs had improved, as well as their understanding of their applications of IMFs to their daily lives. However, with the misconceptions present in the explanation theses students gave, their self-reported improved understanding of IMFs and the application of IMFs to their daily lives is questionable.

Summary for CHEM 114 and CHEM 127 students

Figure 4.15 shows the responses of CHEM 114 and CHEM 127 students to whether they had seen IMFs in their current classes. Five (33% of 15) CHEM 114 students were able to provide examples of a topic in their current class related to IMFs, however, these students were unable to provide a correct explanation to link the topics to IMFs. One (7% of 15) CHEM 114 student indicated they had seen IMFs in their current class but was unable to provide an example of a topic in their class. One (11% of nine) CHEM 127 student was able to provide an example of a topic in her class that related to IMFs, but was also was unable to link the topic to IMFs accurately. Of the students who had seen IMFs in their current class, only one student (Eve – CHEM 127) stated that her understanding of the application of IMFs to her daily life had changed.

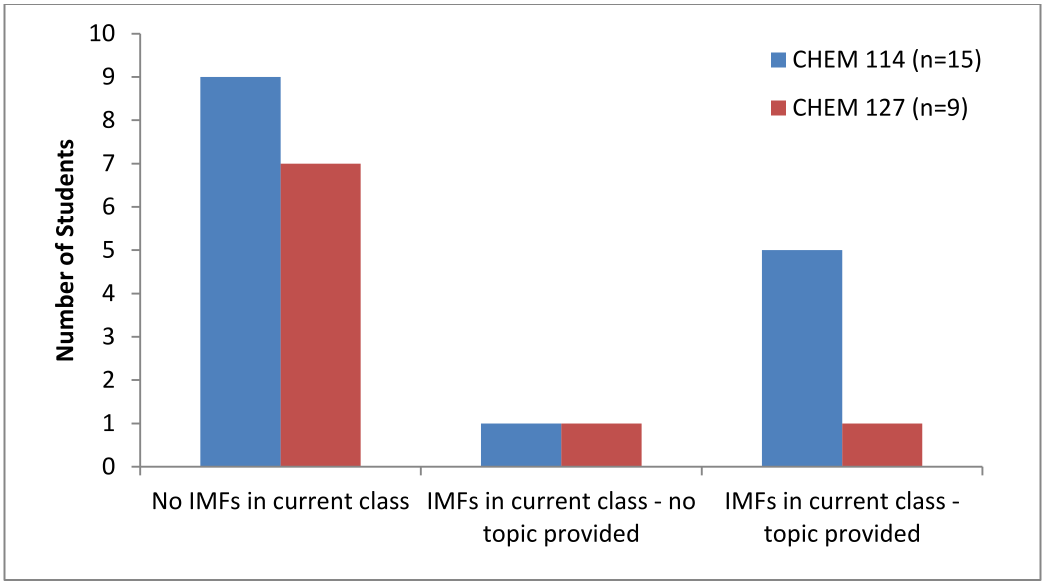


Figure 4.15. CHEM 114 and CHEM 127 students' responses to whether they had seen IMFs in current class.

In summary,

- The majority of both CHEM 114 (nine (60%) of 15) and CHEM 127 (seven (78%) of nine) students reported not learning anything about IMFs in their current class
- Of the six students (CHEM 114 – n = 5; CHEM 127 – n = 1) who provided an area/topic in their current class where they had seen IMFs, four of them indicated an improved understanding of IMFs in general, while three of them stated that their understanding of the application of IMFs to their daily lives had improved.

CHEM 326

Of the 15 CHEM 326 participants, 10 (67%) indicated they either had learnt something new about IMFs, or had seen some application of IMFs in the topics they were covering in their class. Table 4.12 shows the responses of these 10 students to the following questions:

- Can you please provide an example?
- Did what you learn help improve your understanding of IMFs? How?
- Has your understanding of the application of IMFs to your everyday life changed? How?

These 10 students were able to provide topics from their current class that related to IMFs. The topics ranged from chemical reactions to discussions about IMFs influencing physical properties of substances, like boiling and melting points. Serena, Venus, Simona, Gael and Petra all talked about IMFs and the influence they have on determining the physical properties of molecules. All five students recognized that the idea of IMFs determining physical properties was something they had dealt with previously, but now in CHEM 326 they were "building off" (Serena, CHEM 326) previous information, and reinforcing what they had learnt. However, Venus, in explaining why boiling points increased stated that, "…it's going to take more energy to break all these bonds [talking about the carbon-carbon bonds in a nine carbon chain] than it's going to take just to break [a structure with fewer carbons] …" [35] Similarly, Simona talked about the strength of bonds influencing boiling points. According to Simona, "…[a substance's] boiling point is going to be higher because it has to have more energy, and so I think that would make it like exothermic when you break the bond…" [38] Both Venus and Simona have the basic idea that IMFs influence physical properties like melting and boiling points, but like the CHEM 114 and CHEM 127 students, they confuse intramolecular forces with intermolecular forces.

Table 4.12. Responses of CHEM 326 students with new knowledge or applications of IMFs.

	Example provided	Improved understanding of IMFs?	Change in understanding of application of IMFs to daily life
Serena	"…we were talking about alcohols and so we were, um, would rate those on increasing boiling point or melting point…if it has two alcohol groups on it, it will have a higher boiling point than just one alcohol group…it also depends on the number of carbons…there's a rule…actually I think that's with solubility…ah shoot, I don't remember exact trends…" [60-62]	"Yeah … obviously I'm not very polished on it, and, um, I can kind of figure stuff out, but it's mostly educated guessing…" [58-59]	"Um, maybe a little, I mean, I couldn't really give you examples, so…" [65]
Lleyton	"…yeah, I've learned a lot…hydrogen's the strongest, dipole-dipole, the surface area is most important on a van der Waal's…dipole-dipole relates a lot with electronegativity and the size of the molecules, as far as the bond length…basically everything I know about intermolecular forces came from this class so far…" [47]	"Yeah, [my understanding of IMFs has improved]" [48]	"Yeah…I mean, 'cause now I can understand why, uh, bromine is going to break away quicker than chlorine, or a fluorine, just because of the length of the bond there in the dipole-dipole molecule, or why there's, like there's more surface [area] in like a van der Waals' or London dispersion…" [52-53]
Tsonga	"… I think it might have been talked about a little bit, more like, um, elimination, substitution and breaking bonds and forming them again and stuff like that…it usually has to do with hydrogen bonding…just like form new bonds and liquids and stuff like that, and breaking [bonds]…" [46-48]	"Yeah, I think so…um, just because uh, I, the first time you learn it and then you keep seeing it again, and so it's just like it's something that keeps popping up every once in a while…when you see it again and again, so each time you just like, 'oh yeah, I need to make sure I know that because it keeps popping up'…" [50-52]	"Not really…chemistry is academic and like, right now in life, I don't need a whole lot of academics… right now my job consists of making sandwiches, so…" [54-56]
Venus	"…well, kind of new things… now we're looking at more…you know, organic chemistry, so like the Cs and Hs and what would increase the boiling points and what would decrease it…just kind of looking at a new aspect of boiling	"…I think it just gives me more of an understanding, I mean, you can kind of relate your organic chemistry more to like your daily	"… I think if I look more into it, I feel like I've kind of haven't been [applying IMFs to my daily life] when I should, because that's the point of learning about chemistry, is

	point, because I mean in like general chemistry [professor] would give you like H and F together and then he would give you like CCl_4 and you know for sure that the H and F are going to be stronger…[and now], just being able to like, I mean a longer chain will…this would be like a higher boiling point than like a smaller chain…it's going to take more energy to break all these bonds [draws a structure with nine carbons] than it's going to take just to break a smaller bond [draws structure with eight carbons]…" [34-35]	life…maybe like boiling food or maybe like something boils faster than something else, and that could be related to the IMFs…" [37]	being able to apply it to your life, and if maybe I was doing that more, which I should probably start, I would definitely feel that way [that my understanding has improved]…" [39]
Simona	"Um, we just kind of reinforced [IMFs] more…like when we were learning how things bond and like how they become like polar, and then depending on that, like their different physical and chemical properties…like if [the molecules] are more strongly held together, their boiling point is going to be higher because it has to have more energy, and so, I think that would make it like, exothermic when you break the bond…" [36-38]	"…[these reinforcements have improved my understanding] somewhat, but not that much…just because we're not really learning anything new and it's just kind of like we're scratching the surface, but we're not like learning like big details about it…we've done it so many times, I'm starting to remember more things than just in the beginning…" [41-43]	"Yeah, I think I see it more, like, I think about things, that everything is kind of involved with IMFs, more that I've seen it in different classes, so I actually like apply it more…" [45]
Djokovic	"No, but I guess it's [the concept of IMFs] just more detailed and how they are used in chemical reactions…" [46]	"Yeah, I'd say so… like if something is like, has less IMFs, it will break up easier so a group will leave and a new molecule can be formed, so a chemical reaction can take place…" [47-48]	"Yeah, I think it allows like, to conceptualize [IMFs] better and to understand more what's going on around… I can't think of [any specific example]." [52-53]
Gael	"Um, I don't know if it's necessarily new, but there's a lot of like reinforcement and um, I don't know, I guess like being constantly exposed to the same material but like maybe a little more in-depth is kind of what's going on…so like in the beginning of the semester we started talking about um, the properties of organic molecules and those	"Yes…like when you think of, uh, a reaction or something, I don't know, for me the first thing I think of hasn't always been like, what is the IMFs of this molecule and how is that, um, going to interact with	"Um, I think so, um, I guess like…like, I'm in physiology now and so when he's teaching us about the, like the cellular level and how everything changes across the membrane, and all the gradients and stuff, um, it kind of, like I can see myself

	were all very dependent on IMFs… I guess now we are kind of exploring like, um, E2 and SN2 [reactions] and all those mechanisms, an um, I guess like in elimination reactions the stability of the carbocation plays a big role in how it's going to react with the base and stuff…" [42-43]	the IMFs of this molecule. So kind of seeing the importance of it on like an individual molecular level kind of makes it stand out." [49-50]	explaining things more, like to my friends… I'm able to kind of have that um, understanding of how those molecules will interact, like in a proton gradient they're going to go from high concentration to low concentration and stuff like that…" [55]
Agnieszka	"…yeah, well, we've talked about how…like, carbocations and like transition states, with organic molecules as they're going through like reactions, so, it's not like really new, but we've learned to apply it in different ways, so there's again like dipole moments in the transition states of an organic reaction." [34]	"…Yeah… I think intermolecular, like understanding IMFs helps me understand like the actual reaction better that we are learning right now, because it's more fundamental." [34-35]	"No…just probably because I don't think of, in everyday life, of just like particular atoms…" [41-42]
Petra	""‘… I think that like [professor] hasn't necessarily sat down and been like, ‘let's talk about IMFs'…it was more like, ‘let's build on what we already know'. So it's like, ‘you should know what [IMFs] are, so now we're going to talk about how [IMFs] matter in these types of reactions, or within these molecules, and how it affects their shape, and how, like, in order for things to stack or to form this arrangement, there's going to be like strain between them… so I think like not necessarily new information, but like talking about it in different ways." [43]	"I would say so… I think just anytime you're able to go deeper into a subject that you already know about, it improves your knowledge, like whether or not you're really aware…" [44-45]	"Um, I think that I'm more aware of the wider span of things that [IMFs] affects, where in 112, all we needed to know was, ok, these types of solids and what kind of forced they have and like, ‘here's your little list, can you figure out what kind of forces these have?' I think now we have to apply it more…now we have to say, ‘ok, so this is a type of reaction and it's going to use this type of solvent and why?'…so I think it's more applying…" [48]
Rafael	"…well, certainly as far as the strength of dipoles as it related to like resonance. I hadn't realized in like general chemistry that uh, like an alkene, alkyne, CH_3 group will…through the inductive effect will donate electrons and stabilize carbocations and stuff…the kinds of intermolecular forces hasn't changed, but things that will affect the degree to which something has dipole, I see a little bit of change in…" [36-37]	"Yes, definitely" [44]	"I don't know that my understanding of it has like fundamentally changed, it's just sort of more stuff has gotten added on to it…the more I think about it, [at first it was like], ‘here are the intermolecular forces and that's, you know very straightforward', and everything can be grouped into one of those, but I think the more I learn about it, the more I learn that there is a lot of variety between [the forces]…" [47]

On the other hand, Serena also identifies that IMFs have to do with determining physical properties of molecules, but she was unable to give a clear explanation because she could not "quite remember the trends…" [30]

Furthermore, Rafael, Djokovic, Agnieszka, Tsonga and Gael talked about IMFs and chemical reactions. Both Djokovic and Tsonga talked about chemical reactions in relation to molecules and bonds breaking up and forming new molecules – which are examples of intramolecular forces and not intermolecular forces. Gael, Agnieszka and Rafael talked about chemical reactions in relation to carbocation, and discussed how IMFs play a role in the stability of the transition areas of chemical reactions.

Lleyton was the lone student in CHEM 326 who stated that he had learnt something new about IMFs in his current class. Lleyton, a transfer student, mentioned in his interview that CHEM 326 was the first class he had heard about IMFs, as it was not discussed in the chemistry classes he had taken at his previous college. According to him, "…basically everything I know about intermolecular forces came from this class so far…" [47]

Of the 10 CHEM 326 students able to give examples of topics from their class that related to IMFs, Tsonga, Venus, Simona, Serena and Djokovic, gave explanations that had some sort of misconception present. The main misconception present in this study was the confusion between intramolecular forces and intermolecular forces (IMFs), and this will be discussed in more detail in CHAPTER 5 (Cross Analysis). All five students (Tsonga, Venus, Simona, Serena and Djokovic) believed that they had somewhat improved their understanding of IMFs, even with misconceptions present in their explanations. When these students were asked if there was a change in their understanding of the application of IMFs to their daily lives, only two of them, Simona and Djokovic stated that they believed there was an improvement in their understanding of the application of IMFs to their daily lives.

The other five students, Rafael, Petra, Lleyton, Agnieszka, and Gael, were able to give some explanation that linked IMFs to the topic, with no apparent misconceptions. These five students indicated they had improved knowledge of IMFs in general, while four of the five stated that they were now more aware of the applications of IMFs both in their daily lives and in their classes.

Summary for CHEM 326 students.

Figure 4.16 provides a summary of the responses of CHEM 326 students to whether they had seen IMFs in their current class.

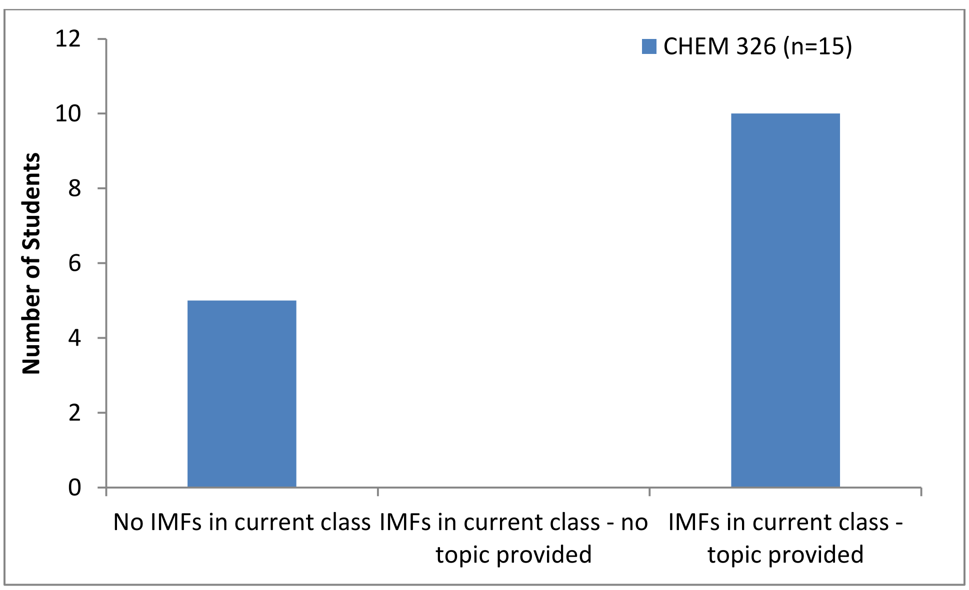


Figure 4.16. CHEM 326 students' responses to whether they had seen IMFs in current class.

Ten (67% of 15) of the CHEM 326 students were able to provide examples of a topic in their current class related to IMFs. Of these ten, five of them were able to provide a correct explanation to link the topics to IMFs, while the other five had misconceptions present.

In summary,

- The majority of CHEM 326 students (10 (67%) of 15) reported seeing topics in their current class that related to IMFs and were able to give examples of a topic,
- All ten students indicated an improved understanding of IMFs in general, while six of them stated that their understanding of the application of IMFs to their daily lives had improved.

Student attitudes towards chemistry

As stated in the literature review, for the purpose of this study, attitude is defined as a set of affective and cognitive reactions towards a certain object that influences the way an individual responds (or behaves) towards that object. The following affective domains were investigated in relation to attitudes in this study:

- Perceived relevance of chemistry
- Motivation to learn chemistry
- Self-reported attitudes towards chemistry
- Self-reported attitudes towards specific chemistry course

Perceived relevance of chemistry

To address this question, the students were asked a question similar to one asked in the survey (Appendix E), "Do you believe that chemistry is relevant to your daily life?" The responses to this question were categorized as follows:

- Yes, chemistry is relevant to my daily life
- No, chemistry is not relevant to my daily life, but it is relevant to my future career
- No, chemistry is not relevant to my life at all.

Figure 4.17 shows how students in CHEM 114, CHEM 127 and CHEM 326 answered the relevance question.

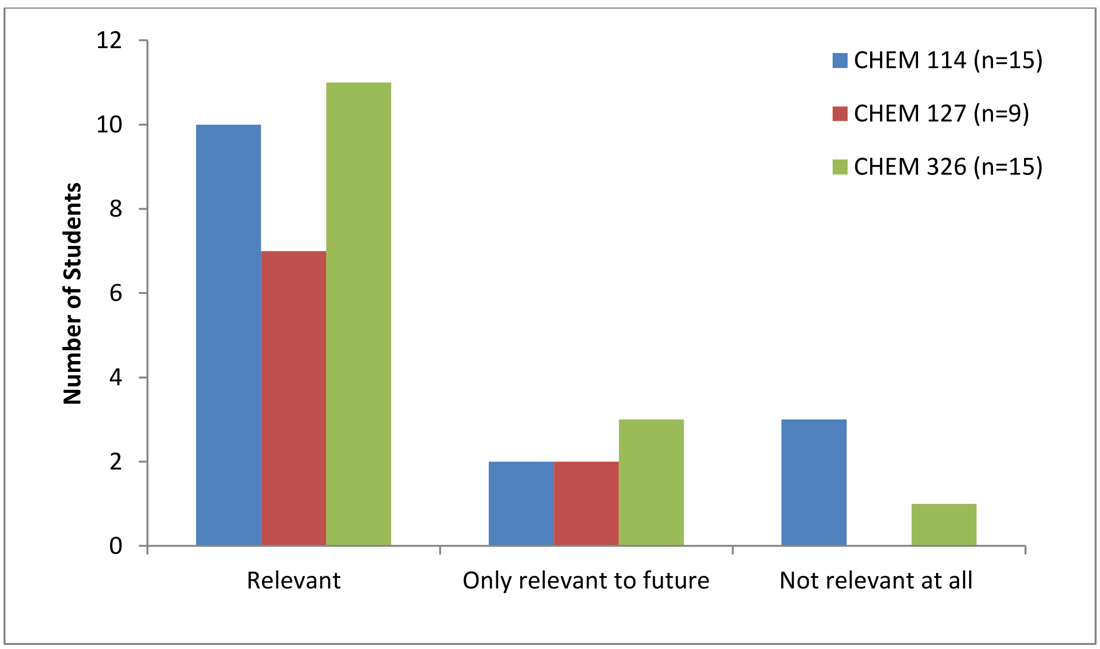


Figure 4.17. Perceived relevance of chemistry to students' daily lives.

The majority of the student participants in all three classes believed chemistry was relevant to their daily lives (CHEM 114 – 10 (67%); CHEM 127 – seven (78%); CHEM

326 – 11 (73%)). Two (13%) CHEM 114 students, two (22%) CHEM 127 students and three (20%) CHEM 326 students believed that chemistry was only relevant to their future careers, and only one student (7%) in CHEM 326 and two students (13%) in CHEM 114 believed chemistry was not relevant to their lives at all. It is interesting to see that even after the general chemistry series, there are still CHEM 326 students who believe chemistry is not relevant to their daily lives.

Table 4.13 shows student quotes about their perceived relevance of chemistry to their daily lives.

Table 4.13. Student quotes about perceived relevance of chemistry to daily lives.

Name/Class	
Petra/CHEM 326	"…you don't have to think about chemistry every day for it to be relevant in your life, like I know that I am made up of molecules…so it has to be relevant, whether or not you think about it…if you do have to think about it like for your major or for your career, then it only becomes more relevant…" [16] **(relevant)**
Deji/CHEM 114	"… I guess you see the basic chemistry in physics…I like cooking and, uh, there's a lot of chemistry involved in cooking…"[27-28] **(relevant)**
Sewa/CHEM 114	"…the way [professor] explains it is that it's the study of stuff…everything you know in life is chemistry…the more we learn about it, the more I realize that literally everything is chemistry." [20] **(relevant)**
Tinuke/CHEM 114	"I would say [chemistry is relevant], I mean, it's like involved in everything, basically." [14] **(relevant)**
Mordecai/CHEM 127	"Uh, yeah [chemistry is relevant] …everything that's manufactured, everything that we come in contact with, at some point, it's probably been looked at by a chemist. Your water bottle, like that's all chemistry." [13-14] **(relevant)**
Phoebe/CHEM 127	"Yes, I do [think chemistry is relevant] …chemistry is just kinda like everywhere around us. Like the different foods we eat, like the reason why, I don't know, like the weather outside, stuff like that…" [15-16] **(relevant)**
Esther/CHEM 127	"Yeah [I think chemistry is relevant] …because without chemistry, without the knowledge of chemistry then we won't know how our bodies really function and how everything else works…" [24-25] **(relevant)**
Agnieszka/CHEM	"[chemistry is] not like really relevant [on a day to day basis], but I can

326	see how… I guess like in a profession, it's important to know the stuff that we're learning." [14] **(only relevant to future career/major)**
Tutu/CHEM 114	"…the only reason it would apply to my daily life would be doing homework, but other than that, not really…"[9] **(not relevant)**
Akin/CHEM 114	"… I mean some of [chemistry is relevant], but the majority of it, I'd say no [it isn't relevant]… I guess it's relevant for basis of other stuff [like becoming a doctor] that might be important, but daily life, I'd say it's not important… " [12, 16] **(only relevant to future career/major)**
Serena/CHEM 326	"[Is chemistry relevant] to everyday life? No. To my future career? Possibly." [17] **(only relevant to future career/major)**
Naomi/CHEM 127	"…it will when I become a pharmacist." [14] **(only relevant to future career/major)**
Zipporah/CHEM 127	"Yes and no [chemistry is relevant]. Like some of the areas I feel like, well, I don't really have to apply that, like it's not really that relevant, but for like my major and stuff, if I want to pursue that, then I feel like I'd be using that every day." [8] **(only relevant to future career/major)**

Summary of perceived relevance of chemistry to daily lives

The majority of the student participants in all three classes believed that chemistry was relevant to their daily lives (Figure 4.17). Two (13% of 15) CHEM 114 students, two (22% of nine) CHEM 127 students and three (20% of 15) CHEM 326 students believed chemistry was only relevant to their future career/major. Of the students that believed chemistry was not relevant to their lives at all, three (20% of 15) were from CHEM 114 and one (7% of 15) was from CHEM 326.

Motivation to learn chemistry

To address this question, the students were asked the following question, "Do you feel like you are motivated to learn chemistry? Why? / Why not?" (the interview protocol can be found in Appendix F). The responses to this question were categorized as follows:

- Motivated to learn chemistry because the student finds it interesting, in addition to other reasons (intrinsic motivation)

- Motivated to learn chemistry **only** because it is necessary for major/future career (extrinsic motivation)
- Not motivated to learn chemistry at all

Figure 4.18 shows the reasons for motivation for CHEM 114, CHEM 127 and CHEM 326 students.

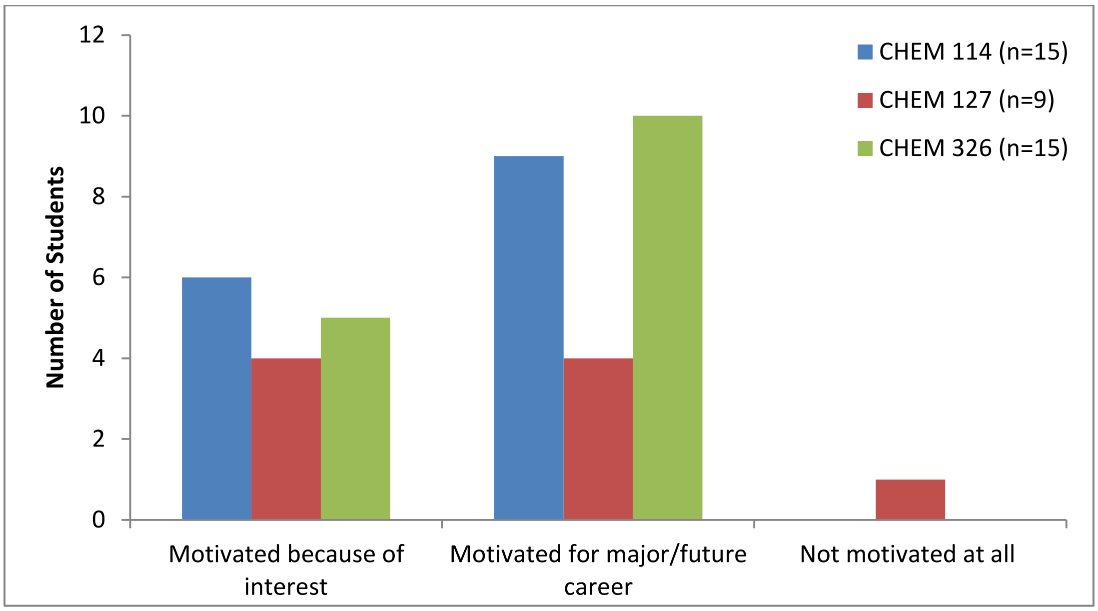


Figure 4.18. Motivation to learn chemistry for CHEM 114, CHEM 127 and CHEM 326 students.

The majority of the student participants are motivated to learn chemistry, either because they are interested in chemistry or because their field of work requires some knowledge of chemistry. Interestingly, the only student in this study who stated that they were not motivated to learn chemistry was in CHEM 127 – a chemistry course for majors/honors students. When asked if she was motivated to learn chemistry, Keturah responded,

> "Um, not right now…'cause I don't… I feel like I'm not pressured. Whereas in my other classes, I'm pressured to do all my homework, and chemistry is, you go to class, you take notes and you really don't do anything until [professor] gives you an assignment, or before a test." [43-44]

Keturah came into the interview session feeling very dejected because she was not doing as well in her chemistry class as she would have liked. She said, "[sighs], to be honest, I'm having a tough time…I don't know if it's the material that I'm not understanding, or like…I don't know exactly what [professor] wants as an answer [on an exam]." [6-7] She also complained about not having a lot of homework, which was one of the reasons she was not motivated to learn chemistry. This scenario is unique in this study, and raises several questions like, "how does assigning homework influence students' motivation to learn?" and "What role do instructors believe assigned work plays on students' performance and motivation?" These are questions that should be further investigated.

Table 4.14 shows quotes from students regarding their motivation to learn chemistry.

Summary of motivation to learn chemistry

The majority of the student participants are motivated to learn chemistry, either extrinsically (for their careers/majors) or intrinsically – because of their interest in the material. Most CHEM 114 (nine (60%) of 15) and CHEM 326 (10 (67%) of 15) students are extrinsically motivated to learn chemistry, while in CHEM 127 there is an even split between extrinsic (four (44%) of nine) and intrinsic (four (44%) of nine) motivation.

Table 4.14. Student quotes about their motivation to learn chemistry.

Name/Class	
Deji/CHEM 114	" [I'm motivated because]…like if I want to get like into a…health field, I kinda need to know some of this stuff probably for like graduate school…the interest in the sciences too also motivates me to learn…" [78-79] **(interest)**
Folake/CHEM 114	"[I'm motivated to learn chemistry] because it's part of my major and I know I'll be seeing more of it, so if I don't get it now, it will be impossible to get in the future, and I find it interesting…" [61] **(interest)**
Phoebe/CHEM 127	"…yes [I am motivated to learn chemistry] …I think because I just really enjoy it, and I don't want to do bad in it, and I want to, I just want to have a better understanding of it." [50] **(interest)**
Caleb/CHEM 127	"…uh, yes [I am motivated to learn chemistry] …it makes sense, it's the only thing I like and it explains a lot…" [43-44] **(interest)**
Agnieszka/CHEM 326	"…yeah [I am motivated to learn chemistry] … because it is very logical, and I like learning concepts that you can actually like make sense of." [46, 48] **(interest)**
Rafael/CHEM 326	"…yes [I am motivated to learn chemistry] …I just want to learn it, it's one of the few classes I have, where almost every time I go to class, I feel like I'm going to learn something new…" [55] **(interest)**
Tsonga/CHEM 326	"…because I need an A – a B is acceptable…pre-dental is usually very competitive, so the better grades, the better chances of getting into dental school…" [65-66] **(major)**
Petra/CHEM 326	"Um, I think I am [motivated] because I want to get a good grade so I can get into the pharmacy program… I'm motivated to learn it to the level I need it…" [50] **(major)**
Feyi/CHEM 114	"I'm motivated to learn it not very much because of just pure interest…mostly because I want to get the major…" [68] **(major)**
Akin/CHEM 114	"Yeah, I'm motivated to…probably get a good grade in chemistry, not so much like I have this desire to really want to know it." [76] **(major)**
Eve/CHEM 127	"Um, yes [I am motivated to learn chemistry] because that's what I want to major in, so if I don't really do good at it, I'm kind of screwed." [42] **(major)**
Naomi/CHEM 127	"Yeah [I'm motivated to learn chemistry] …to get good grades…to get into pharmacy school…" [42-44] **(major)**
Dominika/CHEM 326	"…motivated, not really to learn it, [but] to get a good grade…" [67] **(major)**

Self-reported attitude towards chemistry

Students were asked the question, "How do you feel about chemistry?" and their responses were categorized as follows:

- I like/love chemistry (positive)
- I don't mind it/ I don't care either way (neutral)
- I don't really like chemistry (negative)

Figure 4.19 shows students' self-reported attitudes towards chemistry broken down by class.

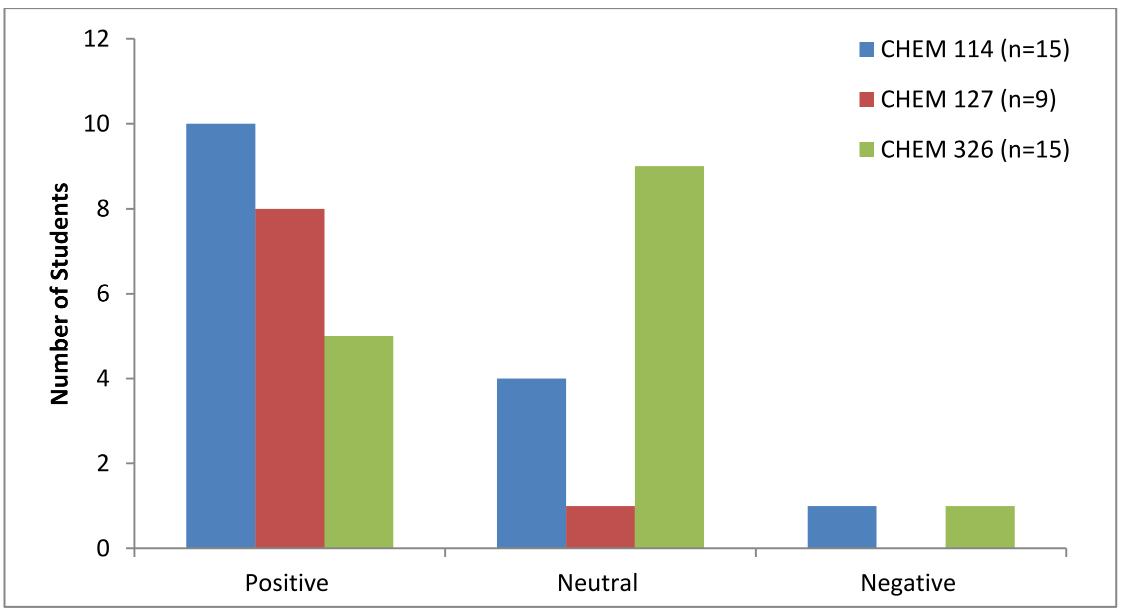


Figure 4.19. Students' self-reported attitudes towards chemistry as a discipline by class.

Most of the students self-reported either positive or neutral attitudes towards chemistry. The majority of CHEM 114 (10 (67%) of 15) and CHEM 127 (eight (89%)of nine) students reported positive attitudes towards chemistry, while the majority of CHEM 326 students (nine (60%) of 15) reported neutral attitudes towards chemistry. Only two students of the 39 participants (one from CHEM 114 and one from CHEM 326) reported negative attitudes towards chemistry as a discipline. Table 4.15 shows student quotes regarding their attitudes towards chemistry as a discipline.

Table 4.15. Quotes about self-reported attitudes towards chemistry as a discipline.

Name/Class	
Lara/CHEM 114	"Um, I like chemistry because it's kinda like math…" [51] **(positive)**
Tunde/CHEM 114	"I like chemistry overall, but there's parts of it that aren't quite as interesting to me, um, partially because they don't apply as well to my major…" [7] **(positive)**
Agnieszka/CHEM 326	"…it's interesting…it can be challenging to understand the concepts, but I like learning it…" [7] **(positive)**
Phoebe/CHEM 127	"I really enjoy chemistry, I like the challenge of it, I think it is very interesting and it's very applicable to life." [8] **(positive)**
Titilayo/CHEM 114	"… I don't mind chemistry…it's not a super, super hard subject for me, it's not super easy either…" [5] **(neutral)**
Fabio/CHEM 326	"Um, sometimes I enjoy it, most of the time I'd say I don't…" [9] **(neutral)**
Tutu/CHEM 114	"…it's not my favorite, but, uh, I want to learn, like I want to get really good at it." [5] **(neutral)**
Keturah/CHEM 127	"…to be honest, I'm having a tough time [with chemistry]…in high school I really liked chemistry…I thought it came easier to me, but now…it's kind of iffy." [6, 8] **(neutral)**
Serena/CHEM 326	"How do I feel about [chemistry]? Um… I didn't think it was quite applicable, until you know, we started getting into the more detailed, of like the cellular, or like biochemistry and stuff…but, um, I don't particularly like it, I guess." [8] **(negative)**
Feyi/CHEM 114	"I don't really like [chemistry] very much" [10] **(negative)**
Tsonga/CHEM 326	"[Chemistry] is ok, it's not my most favorite subject." [5] **(neutral)**

Summary of self-reported attitudes towards chemistry

The majority of CHEM 114 (10 (67%) of 15) and CHEM 127 (eight (89%) of nine) students reported positive attitudes towards chemistry as a discipline, while most of the CHEM 326 students (nine (60%) of 15) reported neutral attitudes towards chemistry.

Self-reported attitude towards specific chemistry class

Students were asked the question, “How do you feel about the specific class you are currently in” and their responses were categorized accordingly:

- I like the class/The class is cool/interesting/easy
- I do not mind the class/It is not my favorite, but it’s ok
- I really do not like the class.

Figure 4.20 shows students’ self-reported attitudes towards their specific chemistry course broken down by class.

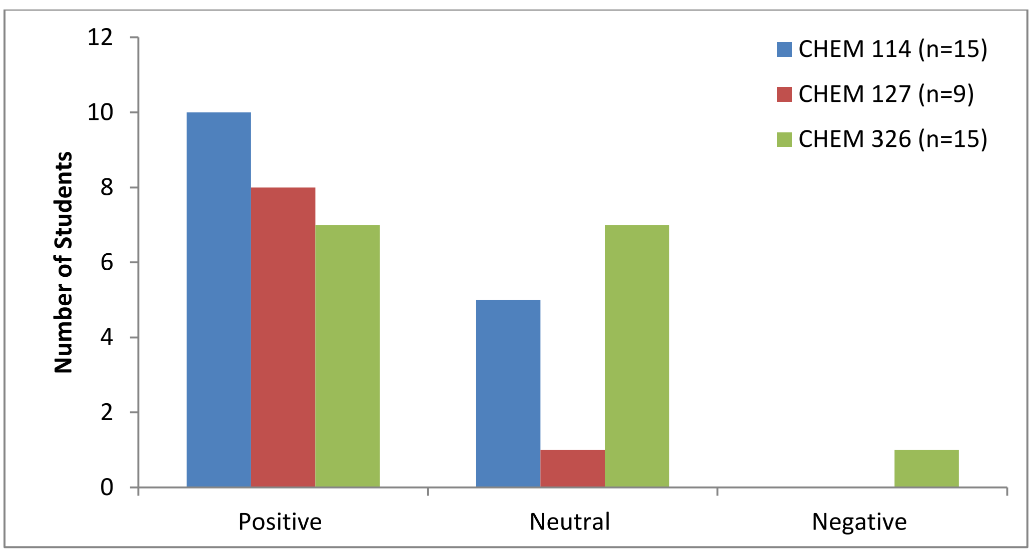


Figure 4.20. Students’ self-reported attitudes towards their specific class (CHEM 114, CHEM 127 or CHEM 326).

The majority of the 39 student participants had either positive or neutral attitudes towards their specific class. In CHEM 114, 10 (67%) of the 15 participants self-reported positive attitudes towards CHEM 114, and five (33%) of the 15 reported neutral attitudes towards CHEM 114. Eight (89%) of the nine CHEM 127 students reported positive attitudes towards CHEM 127, and only one (11%) reported a neutral attitude towards CHEM 127. In CHEM 326, seven (47%) of the 15 students reported positive attitudes towards CHEM 326, while another seven (47%) reported neutral attitudes towards CHEM 326. Only one student reported a negative attitude towards their specific chemistry class – CHEM 326. As stated earlier in the survey data, these results are not very surprising. My interactions with students have shown that students typically enjoy the math based chemistry classes, where they can put numbers into an equation and get the right answer, compared to chemistry classes like organic chemistry, where numbers plugged into an equation cannot be used to obtain answers.

Table 4.16 shows quotes from students regarding their attitudes towards their specific chemistry course.

Table 4.16. Quotes about student attitudes towards their specific chemistry course.

Name/Class	Attitude towards CHEM 127 specifically
Keturah/CHEM 127	"After yesterday's test, I don't know if I quite understand everything and why, the reason why behind everything…" [13] (**neutral**)
Priscilla/CHEM 127	"…[CHEM 127] is going pretty good…I'm liking it, just in that it's easier to visualize the stuff that we're talking about…" [8-9] (**positive**)
Naomi/CHEM 127	"I actually like [CHEM 127] a lot better than 115… I mostly enjoy it because I understand what's going on…and [professor] is a really good professor." [10, 13] (**positive**)
Deji/CHEM 114	"… I do like it… it's a little bit harder than 112… I didn't try very hard in 112, but it's kind of kicking my butt now, in 114…" [19-20] (**positive**)
Tutu/CHEM 114	"I actually like [CHEM 114] better than 112… I'm just better prepared for 114, and I feel like 114 is less equations and stuff, compared to 112, and so I like it a lot more…"[7] (**positive**)
Akin/CHEM 114	"I enjoy [CHEM 114], it's good… [professor] is a good teacher, and

	last test was hard, but other than that, I've been doing good…" [9] (**positive**)
Ola/CHEM 114	"…it's not bad at all, like [the] first test, I didn't really pay attention because I thought I'd figure it out…but the second test, [I] did better…[CHEM 114] is a lot easier to comprehend and keep up with than 115." [15] (**neutral**)
Gael/CHEM 326	"Um, I'm happy with my grade [in CHEM 326]…it's a lot of work…it's not horrible, it's not easy…" [9] (**neutral**)
Tsonga/CHEM 326	"[I] really don't like [CHEM 326]… I don't think the teacher teaches that well…" [9-10] (**negative**)
Lleyton/CHEM 326	"I like [CHEM 326] a lot, it's awesome… [professor] is really interactive…he relates everything in the real world, which is something a lot of professors have a hard time doing." [11-12] (**positive**)
Dominika/CHEM 326	"I think [CHEM 326] is very difficult, definitely have to put a lot of work into it if you want to do good, um, but, yeah, I like it. I enjoy reading about it. I really didn't think I was going to…" [9](**positive**)
Safarova/CHEM 326	"Um, [I feel] average [about CHEM 326]…not my favorite class, but I can't complain with it either." [9] (**neutral**)

Summary of self-reported attitudes towards specific chemistry course

The majority of the CHEM 114 (10 (67%) of 15) and CHEM 127 (eight (89%) of nine) had positive attitudes towards their specific chemistry course. Seven (47% of 15) CHEM 326 students stated they had positive attitudes towards their specific chemistry course, while another seven (47% of 15) said they had neutral attitudes towards their specific chemistry course.

Teaching strategies used by chemistry professors to facilitate transfer

After interviewing several students and realizing the process of transferring knowledge from the chemistry class to both daily life and other classes outside of chemistry was a struggle, I decided to interview to the faculty members teaching these classes. All the faculty participants were given pseudonyms from the Disney® movie, The Lion King.

The bullet points below briefly give an overview of the faculty participants and their teaching philosophies.

- Dr. Mufasa routinely teaches the general chemistry series for science majors, and has taught chemistry for 21 years. Dr. Mufasa believes that there are multiple aspects of teaching, but thinks that it is very important to teach the material in an organized and logical manner. According to him, "I like it when the material builds on itself…students hopefully can see that this part is related to this part, which is related to that part…you're helping them build a conceptual framework, which will help them understand [the material]." [**2**; 4]*
- Dr. Zazu routinely teaches organic chemistry for science majors and has taught chemistry for about 35 years. Dr. Zazu believes in teaching the material using multiple ways so his students are able to connect to the material, and so as not to lose the interest of students. According to him, the delivery of the material should "…fit the audience in front of you…in a way that will be appealing [to students]…," [9] and in a way that connects the material to their various backgrounds/majors.
- Dr. Pumbaa routinely teaches the general chemistry sequence, both for science majors and for chemistry/biochemistry majors and has taught chemistry for about seven years. Dr. Pumbaa believes in getting students to think beyond the content of the course. According to him, "…it's not all about the content, I mean, content is great for them to learn… [but] it's the skills that they actually can take out of this class… I focus mostly on getting them to think…to problem solve, to ask questions, to understand what learning is…" [**2**, 4]

*The number in bold ([**2**]) represents the interview number, while the other number ([4]) represents the statement number from the interview transcripts.

From the quotes above, and the tone of the interviews conducted, all three faculty participants in this study expressed teaching philosophies that centered on the students. This indicates that these faculty members are concerned with helping their students excel. The interview questions are in Appendix G.

One of the questions asked during the interviews was, “Do you believe there are connections between chemistry courses?” I asked this question because I believe that if an individual is unaware of connections between courses, then there can be no conscious effort to facilitate transfer of the connected knowledge to other classes. As expected, all of the faculty participants agreed that chemistry classes were connected. I asked the participants why they thought there were connections between these classes, and the following quotes show their responses:

> “In some ways, you could argue that all other chemistry courses are just applications of gen chem. General chemistry basically introduces all concepts that a chemistry student will see all throughout their career…” ~Dr. Mufasa [**2**, 14]

> “…we wouldn’t be teaching general chemistry if there weren’t connections that [students] would be building on to later on…you’re teaching them the fundamentals to sort of apply those to challenging concepts later on…” ~Dr,. Pumbaa [**2**, 12]

> “…without general chemistry, I find it very hard to deliver any chemistry…it is not appealing to some students, but I’m a believer that you have to tell the students why I’m giving [the information to] you this way…ok, you’re taking math…physics…general chemistry, why is that? Because this is the solid background to move on to the chemistry, biochemistry, mammalian physiology, anatomy, you name it…” ~ Dr. Zazu [14]

All the faculty participants agreed that there were connections among chemistry courses. However, I probed further and asked them to give me classes they believed connected to the specific course(s) they taught. The participants were all able to give at least one specific course outside chemistry, relating to the course they taught. Dr. Mufasa highlighted physics and economics relating to his general chemistry courses. According to him, "…the concepts of equilibrium are applicable to economic systems, social systems, and physical systems…" [**2**, 23] Dr. Zazu believes his organic courses relate to biochemistry and biology, which is important for the pre-professional majors in his classes. According to Dr. Pumbaa, "…I think all the STEM fields…biology, physics…mathematics, algebra to calculus… probably have connections [to general chemistry]. [**2,** 19]

All three faculty participants were aware of connections between the specific chemistry course(s) they taught to other chemistry courses, as well as courses outside of chemistry, and all stated that they believed it was important for students to be able to make these connections. Of the three participants, two of them stated that they emphasized the importance of making these connections between courses to their students. According to Dr. Zazu, "…if we do not [emphasize the importance of the outcomes] I think we fail in our teaching outcome. You have to show the students that we are part of the learning outcome…" [18] Dr. Pumbaa echoed the same sentiments as Dr. Zazu. His comments were as follows:

> "…if there weren't connections [between other classes] then we will not be teaching these advanced level classes…you would have to build connections to more applicable things in the fields, so that they have a better understanding of

> what's going on and how to use these skills and [the] content in future practices that they're going to have…" ~ Dr. Pumbaa [**2,** 21]

On the other hand, Dr. Mufasa stated that he did not emphasize the importance of connection between the specific chemistry course(s) he teaches and other classes. According to him, "…I point [connections to other classes] out when I find it appropriate…," [**2,** 29] meaning, he does not go out of his way to find ways to connect the material he teaches to other classes.

When I asked the faculty participants about their perceived importance of students making connections between their chemistry courses and their daily lives, two of them stated that they emphasized the importance of students making connections between their chemistry course and their daily lives. According to Dr. Mufasa, he makes a conscious effort to connect the material to the "real world." He believes connection to the real world "…is an important connection to make, just so that they understand the importance of the topic [being taught]." [**2,** 31] Dr. Zazu also agreed with this rationale.

Dr. Pumbaa however, had a different view on the importance of making connections to the students' daily lives. According to him, "…I usually give some [real world] examples…but it's not a big emphasis… I don't really think [making connections to daily life] changes the way they learn the material. It's more like they'll get the concept…but they're more worried about the math associated with it than the concept itself." [**2,** 45, 49]

In summary, the faculty participants believe:

- There are connections between chemistry classes and classes outside of chemistry and,

- It is good for students to be able to make connections between their specific chemistry courses, and other classes, as well as to their daily lives.

To get an idea of the different techniques used by the faculty participants to facilitate transfer from class to class and to daily life, I asked the following questions:

- “What are some techniques you use to facilitate knowledge transfer from class to class in your students?”
- “How do you help your students make connections between what that learn in class and their daily lives?”

Techniques used to facilitate transfer from chemistry class to other classes

There were two main ideas from the faculty participants regarding techniques used to facilitate transfer from class to class. Dr. Pumbaa stated that if the students understood the material very well, they would be able to transfer the knowledge from their class to other classes, so he focused on getting students to understand the material. Dr. Pumbaa engages his students in conversations and asks questions that he believes helps the students build the connections. According to him, “…once [the students] are able to understand the knowledge…then they’re probably able to transfer it to organic chem, or gen chem two, or whatever other class it is they’re taking.” [**2,** 36]

The techniques used by Dr. Pumbaa to facilitate knowledge transfer involve making the students think about what they are learning. This process is very student-centered, and to an extent involves the students’ actively participating. Dr. Pumbaa believes these techniques are effective in facilitating knowledge transfer from class to class in his students, and anecdotally measures the effectiveness using students’ test scores.

Conversely, when Drs. Mufasa and Zazu discussed the techniques they used to facilitate transfer from class to class, they both talked about verbally highlighting the connections between classes to their students. Dr. Mufasa tries to "incorporate the vocabulary used in organic [chemistry] into my general chemistry [class]", [**2,** 45] while Dr. Zazu verbally points out topics/concepts that relate to a class taken previously, or to a class the students will take in the future. Interestingly, both Drs. Mufasa and Zazu do not think this is a very effective way to facilitate knowledge transfer. According to Dr. Zazu, who teaches organic chemistry, "…a large percentage of [the students] need more than a reminder…" [23] because he believes most of the students in his class did not pay close attention in their previous classes, and so they do not necessarily retain much from those classes. Dr. Mufasa, who teaches the general chemistry sequence, stated that several students "…behave like rats in a maze, and they don't look past the class, no matter what you do…" [**2,** 46]

Techniques used to facilitate transfer from chemistry class to daily life

The main technique used by all the faculty participants to facilitate knowledge transfer of students from class to daily life was giving examples. However, some of the faculty members were more likely to relate class material to the students' daily lives than others. According to Dr. Pumbaa, "…I usually give some [real world] examples…but it's not a big emphasis." [**2, 45**] The other two faculty participants were more enthusiastic about connecting the class material to the students' everyday lives, and went a little further than just giving examples. Dr. Zazu not only gives his students examples, but also brings in examples (drugs, insect repellant, etc.) to show his class. Dr. Mufasa also gives examples in his class to emphasize the connection between the class and the students' daily lives, and he "…often show[s] movies, um, during the lecture that shows those connections." [**2,** 53]

Chapter Summary

The following are the main points in this chapter:

- The majority of the student participants fell under the minimal level of recollection.
- The majority of these students also fell under the minimal level of transfer to their daily lives; however, most of them were unable to transfer knowledge of IMFs to classes outside chemistry.
- The majority of the student participants self-reported positive attitudes towards chemistry, believed chemistry was relevant to their daily lives and reported they were motivated to learn chemistry because of their future career/major

The next chapter will use these results to address the research questions this study seeks to answer.

CHAPTER 5: CROSS ANALYSIS

Introduction/Overview

In this chapter, the data and trends reported in CHAPTER 4 (Results) will be used to address the sub-research questions and ultimately the overall research question. To review, the four sub-research questions investigated were:

- What are students able to remember about IMFs?
- How are students able to transfer what they have learnt about IMFs to other classes, and to their daily lives?
- How do additional chemistry courses influence this transfer of knowledge to daily life?
- What is the relationship between recollection and transfer and students' attitudes towards chemistry?

Abilities of students to recall information about IMFs

The first sub-research question was, "what are students able to remember about IMFs?" From the data collected in this study, the student participants were mostly able to remember the definition of IMFs and provide examples of types of IMFs discussed in class. The majority of the student participants in this study were able to operate at the first level of Bloom's taxonomy – remembering.[159] These students were able to recall basic knowledge about IMFs by providing the correct definition of IMFs and giving examples of IMFs from class.

The recollection levels of student participants were categorized as high, moderate, low, and minimal levels of recollection (see CHAPTER 4 (Results) for explanation of creation of categories). Of the 39 participants, 29 (74%) were able to give a correct definition of IMFs and 24 (61%) were able to give examples of IMFs from class. A participant's ability to provide a correct definition and examples is consistent with the first level of Bloom's taxonomy – remembering.[159] However, only 11 (28%) of the 39 student participants were able to operate at the next level of Bloom's taxonomy (understanding). These students were able to correctly arrange the three molecules given in order of increasing boiling point and provide an accurate rationale for the answer provided. Figure 5.1 shows a breakdown by class of the students who were able to define IMFs, give examples from class and provide a correct rationale for the correct arrangement of the molecules given.

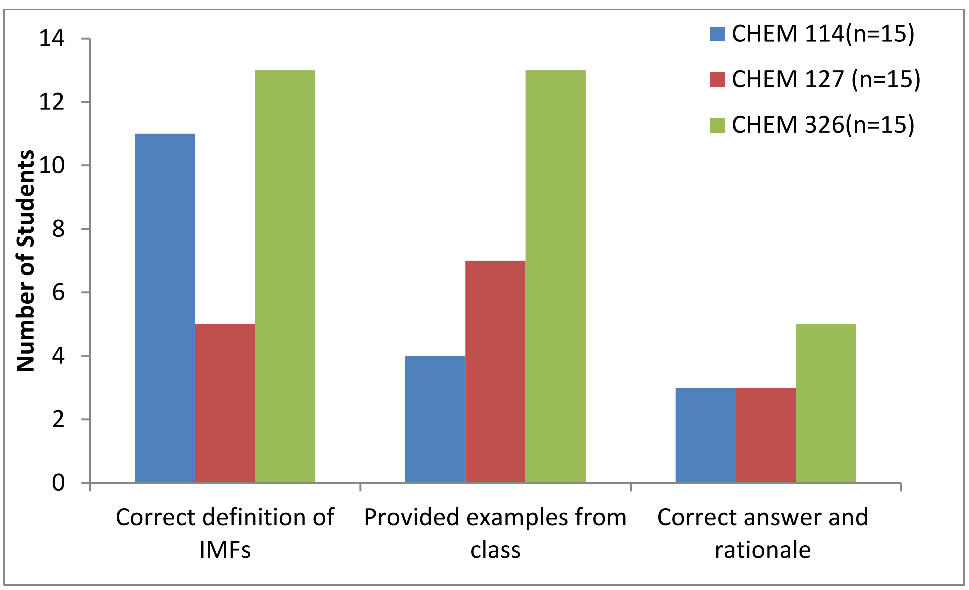


Figure 5.1. Number of students who were able to provide a correct definition of IMFs, provide examples from class and correctly arrange molecules in order of increasing boiling point and provide correct rationale.

In CHEM 114, 11 of 15 students were able to provide a correct definition, four of 15 were able to provide examples from class and three of the 15 were able to arrange the molecules correctly and provide a correct explanation. In CHEM 127, five of nine students were able to provide a correct definition, seven of nine were able to give examples from class, and three of nine were able to arrange the molecules correctly and provide a correct explanation. In CHEM 326, 13 of 15 students were able to provide a correct definition and give examples from class, while only five of the 15 were able to arrange the molecules correctly and provide a correct explanation. It is interesting to note that of the nine CHEM 127 students, even though only five were able to define IMFs correctly, seven were able to give examples of IMFs from class. This is interesting because this trend is opposite in CHEM 114 – more students (11 of 15) were able to define IMFs and less (four of 15) were able to give examples from class.

At this institution, both CHEM 114 and CHEM 326 students were first introduced to IMFs in CHEM 112, while CHEM 127 students first came across this topic in CHEM 115. I observed both CHEM 112 and CHEM 115 when the professors (Drs. Mufasa and Pumbaa respectively) taught about IMFs. I noticed that the CHEM 112 professor spent five 50-minute class periods on the concept, compared to the one class period used by the CHEM 115 professor. In CHEM 112, during the first lecture on IMFs, the professor spent some time talking about why IMFs were important and talked about different physical properties of molecules in relation to IMFs. This professor also asked questions using TurningPoint® (an interactive polling instrument) to reinforce how different IMFs influence the physical properties of molecules. The following are examples of TurningPoint® questions used in CHEM 112:

- How do molecules interact with each other?
- Which should have a higher melting point: CCl_4 or KF?
- What happens when water is heated producing a gas?

Dr. Mufasa (CHEM 112) made sure to explain the answers to most of the TurningPoint® questions. From my observations, I found that there was a lot of reinforcement of the concept of IMFs in CHEM 112 by using TurningPoint® questions, worksheets and verbal emphasis from the professor. On the other hand, in CHEM 115, the IMFs lecture lasted for about half of one 50-minute class period, and a little less than half of another 50-minute class period, for a total of about 40 – 45 minutes. During the first half of the lecture on IMFs, the CHEM 115 professor defined IMFs briefly and talked about the different types of IMFs. During the next lecture session, the professor gave students molecules like pentane and ethanol and asked what types of IMFs were present in the molecules.

This difference in the teaching methods used by the CHEM 112 and CHEM 115 professors and the levels of reinforcement and emphasis could play a role in the ability of the students to define IMFs. It can be argued that the CHEM 114 and CHEM 326 students had heard about IMFs more than the CHEM 127 students had, and this constant reinforcement was why more of the students were able to provide definitions of chemistry. However, if that was the case, then more CHEM 114 students should have been able to provide examples from their class.

It does seem counter-intuitive that more CHEM 127 students gave examples of IMFs in their classes compared to CHEM 114 students, so I decided to go back and look at the interview transcripts. The question I asked the students was, "can you give an example of IMFs from class that was meaningful to you?" At the beginning stages of the interview process, if the student participant was unable to give a "meaningful example" I moved on to the next question. However, as the interviewing process continued, I started asking the students who were unable to give a "meaningful example" to provide any example they remembered from class. Since CHEM 114 was the first class I interviewed, my failure to be persistent in asking for examples from their class may have influenced the number of students who were able to provide examples from their class.

Of the 24 students who provided examples from class, 14 (58%) of them gave examples involving water. Below are some quotes from the students:

> "…I guess the hydrogen bonds were pretty meaningful, 'cause that's like , that means the water molecules, like that's why water makes droplets and why it like, like, that helps it be pulled up into plant stems and stuff…" ~ Feyi, [28] CHEM 114
>
> "Um, so, like…I think of like hydrogen bonding, so like, like when you have like adhesion or whatever, with water, I don't know, that's just what I think of. It's the first thing that comes to mind." ~ Phoebe, CHEM 127
> "Um, I guess water, it is every day, and you use it and it is hydrogen bonding." ~ Djokovic, [26] CHEM 326.

Of the 10 (42% of 24) students who did not mention water in their examples, five of them talked about hydrogen bonding in general. The majority of the students (19 (79%) of the 24 students) who were able to give examples of IMFs from class gave examples that centered on something they interact with every day – water. Dr. Mufasa (CHEM 112) used water multiple times when he talked about IMFs. He talked about hydrogen bonds in relation to water as well as other materials, including DNA. He also talked about surface tension in water and its influence on formation of droplets. This strengthens the idea that reinforcement of material does increase the ability of students to remember. [157] These students have heard terms like "hydrogen bonding" and "water" multiple times and so it is natural for them to default to those examples. This phenomenon ties into Detterman's theory of education that postulates that for an individual to know something, they must be taught. This theory suggests that educators cannot teach general principles and assume that based on those general principles, students grasp specific ideas/concepts. [105] To test this theory further, it would be interesting to carry out a study investigating how frequently an instructor uses certain examples in a class and how this repetition influences students' abilities to remember.

Three (20% of 15) CHEM 114 students, three (33% of nine) CHEM 127 students and five (33% of 15) CHEM 326 students were able to arrange the three molecules provided in the correct order of increasing boiling point <u>and</u> provide the correct rationale for this arrangement. Ideally, all 11 students that were able to provide a correct rationale should also have been able to define IMFs correctly and provide examples from class. However, this was not the case. Of the three CHEM 114 students, one of them was unable to give an example of IMFs from class, and one of the three CHEM 127 students was unable to define IMFs correctly. Conversely, all five CHEM 326 students were able define IMFs, give examples from class, and provide the correct rationale. That all five CHEM 326 students were able to do these things, compared to their CHEM 114 and CHEM 127 counterparts could be because they had been exposed to the concept of IMFs for a longer period (at least one extra semester), leading to reinforcement of these ideas for the CHEM 326 students. This reinforcement by instructors, discussions they may have had with their peers, and even reading from the textbook could influence the levels of recollection for these CHEM 326 students. [105, 160]

In conclusion, even though there were some students, that exhibited high levels of recollection, a majority of the student participants in this study were unable to go beyond remembering facts, like the definition of IMFs and giving examples of types of IMFs.

Students' abilities to transfer knowledge

The second sub-research question this study investigated was, "how are students able to transfer what they have learnt about IMFs to other classes, and to their daily lives?" The data collected from this study showed that the knowledge students are able to transfer about IMFs to their daily lives is very rudimentary. Most students were able to give an example in their daily lives that could be related to IMFs, but were unable to correctly explain how IMFs were tied to the examples they provided. Regarding transfer to other classes, the data from CHEM 127 and CHEM 326 students showed that students were able to transfer very little about IMFs to other classes outside chemistry. In fact, more students were able to transfer knowledge to their daily lives compared to other classes. One reason for this could be that the professors spend more time giving real world examples than they do making connections to other classes.

Transfer to daily lives

Of the 39 student participants, 29 (74%) were able to give examples from their daily lives that could be related to IMFs. Figure 5.2 shows a breakdown by class of students' abilities to provide examples of IMFs in their daily lives. A majority of students in all three classes were able to provide examples of IMFs from their daily lives – 13 (87%) of 15 students in CHEM 114, five (55%) of nine in CHEM 127 and 11 (73%) of

15 in CHEM 326. It should be noted that more CHEM 127 students were unable to give examples from their daily lives, compared to their CHEM 114 and CHEM 326 counterparts. This is an important note because during their interviews, both Drs. Mufasa (CHEM 112/114) and Zazu (CHEM 326) stated they believed it was important to make these real world connections in the classroom and tried to make those connections in their classes. Conversely, Dr. Pumbaa (CHEM 115/127) stated he did not emphasize real world connections in his class as much.

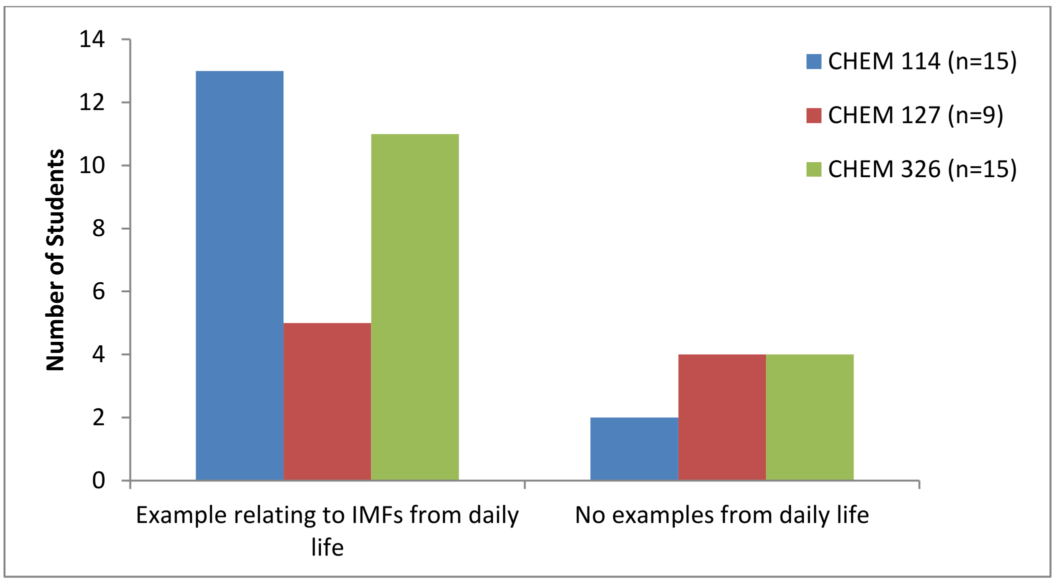


Figure 5.2. Students' abilities to provide examples of IMFs from daily life (by class).

During his interview, Dr. Mufasa, who teaches CHEM 112 (taken by both CHEM 114 and CHEM 326 students) stated that he makes a concerted effort to connect the material he teaches to the "real world." During my observations in CHEM 112, I found that Dr. Mufasa did make an effort to tie real world examples, using mostly water, to what he was teaching. On the other hand, Dr. Pumbaa, who teaches CHEM 115 (taken by

CHEM 127 students) stated, "…I usually give some [real world] examples…but it's not a big emphasis…I don't really think it changes the way they learn the material." [45] During my observations in CHEM 115, Dr. Pumbaa used only one real world example when he talked about IMFs – he gave the example of how geckos used Vander Waal's forces to climb on walls. Based on these interviews and observations, it is not surprising that CHEM 114 and CHEM 326 students were able to give more real world examples compared to CHEM 127 students. According to Johnson and Rutherford[115] it is unreasonable to expect students to transfer information to other classes and to their daily lives "if the ways in which [educators] present material do not indicate that [students] should be doing this." Studies have shown that it is not enough for connections to exist among classes, there has to be a concerted effort by the instructor to highlight and facilitate those connections to the students.[105,115,119,161]

Interestingly, of the five CHEM 127 students who gave examples from their daily lives, four (80%) of them gave examples related to water. This is interesting because Dr. Pumbaa (CHEM 115) did not use water as an example; he used Vander Waal's forces in geckos. This observation suggests that the CHEM 127 student participants were relying on information they had heard from other sources (personal experiences, high school, other college science classes, or even their textbooks). The following are quotes from CHEM 127 students:

> "Uh, water beading up…because if there were no IMFs, it would just disperse, and since there are [IMFs], I see water droplets…" ~ Mordecai, [38-39] CHEM 127

> "Well, like I know if I boil water, that has to break IMFs, but I don't really think about it…" ~ Eve, [37]CHEM 127
>
> "Um, I guess whenever you take a shower and you see the water droplets either coming together or sticking um, on the uh, walls of the shower, it's the cohesive and adhesive forces." ~ Caleb, [32] CHEM 127

In CHEM 114, the majority, nine (69%) of the 13 students, gave examples related to water. This is somewhat expected since water was the primary example given in CHEM 112. The following are quotes from CHEM 114 students:

> "Um, I guess I'll just go with uh, maybe evaporation of water, when you're walking outside and there's water on a hot black top and then after it just gets done raining and then when the sun comes out and it evaporates up, it probably has something to do with [IMFs]." ~ Bayo, [45] CHEM 114
>
> "…um…like ice melting maybe, or like water boiling, 'cause that changes how attracted, temperature affects how molecules are attracted to each other and how tightly the bonds are and how strong the forces are that keeps them together." ~ Sewa, [40] CHEM 114
>
> "Um… I guess wouldn't water be an example…like just because of the way like hydrogen, um, is like H^+ and oxygen is O^{2-} like that affinity causes them to react and um, basically then they form water…that also affects like the different phases of water, like solid, liquid, gas." ~ Tunde, [30-31] CHEM 114

Conversely, only four (36%) of the 11 CHEM 326 students gave examples related to water. This observation was surprising to me because since the CHEM 326 students heard a lot about water as a real world example in CHEM 112, I expected more of them would give examples relating to water. Table 5.1 shows quotes from CHEM 326 students regarding examples of IMFs from their daily lives.

Table 5.1. Quotes – examples of IMFs from daily life (CHEM 326 students)

Example using water	Examples not using water
"…adding like salt to water…the negative charge on the oxygen and the positive on the, um salt…and then they react together? Something like that, sodium I think has the positive." [27, 31] Fernando	"I guess there's like acid/base stuff that um, like the reaction between um, digestion and how you take food in, and your stomach makes acid, that all gets broken down, so I guess there's those interactions there…" [38] ~ Gael
"…like the simple process of like boiling water…just knowing that the bonds are breaking and that's what's causing the boiling of the water…"[30] ~ Venus	"…I mean, it should be like within everything, so like the walls in this building are made up of molecules that would have to have IMFs, that's good, because they are holding up the walls…"[40] ~ Petra
"Um, wouldn't that be like with water technically…you drink it…" [40-41] ~ Tsonga	"…with like adhesion of stuff…" [39] ~Djokovic
"…raindrops, I mean water…if there was no intermolecular force there, then the raindrops wouldn't form, they'd just be hydrogen and oxygen floating around in the atmosphere." [41, 43] ~ Lleyton	"…I guess I always kinda like go back to like baking and cooking, um, depending on the force [IMFs] would be, um, like, going back to boiling points, like if you're making something and you have to like, bring it up to boiling, um, that time would vary." [33] ~Angelique
	"Um, I suppose trying to boil something would be an example." [53] ~ Serena
	"Um, well gasoline boils, you know, really easily…has a low boiling point because it only has Vander Waal's forces, so when you, you know, are putting gas into the car, you see it coming out just because the temperature at which it boils is very low...because the energy required to break the bond between the two molecules is very low, so you don't have to add much heat to it." [32-33] ~ Rafael
	"Um, well the one thing I think is everything has London dispersion…if just everything was floating around [without IMFs], it just would be chaos in the world." [33, 37]~ Safarova

Of the quotes shown in Table 5.1, more of the students who gave non-water examples were able to provide examples that were personal to them. Rafael gave the example of gas, Angelique used an example of baking, while Safarova and Petra gave examples of IMFs holding things around them together. From their quotes, it seems these students have moved from the generic "oh, there is hydrogen bonding in water," and have started to internalize that IMFs are involved in many things all around them. This change in students' thought process could be because they have been exposed to more chemistry (and possibly science) classes and are now able to see IMFs beyond just water example they were given in CHEM 112.

The majority of the students in this study, 29 of the 39, were able to give examples of IMFs from their daily lives. However, only a few of the students were able to correctly tie the examples they gave to IMFs. Of the 29 students who were able to give examples, 14 of them gave no explanation or an incorrect explanation, 10 of them gave partially correct explanations, while only five of them gave a correct explanation. Figure 5.3 shows a breakdown by class of the 29 students' abilities to provide explanations relating their examples to IMFs.

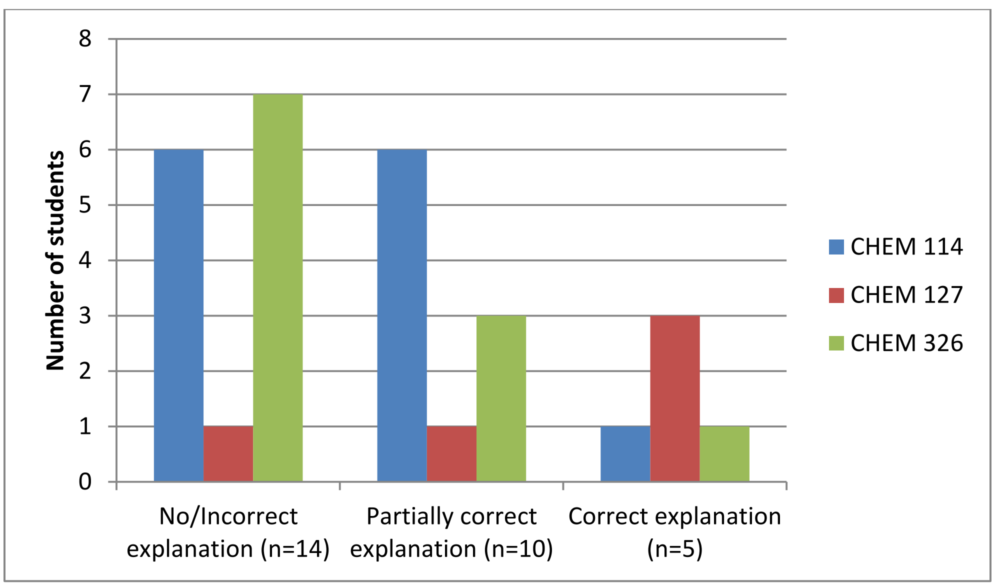


Figure 5.3. Students' abilities to provide explanations for examples provided from their daily lives.

The majority of the CHEM 114 and CHEM 326 students gave no/incorrect or partially correct explanations, while more CHEM 127 students gave a correct explanation. So even though the CHEM 326 student participants are going beyond the water example, they still struggle with understanding the reasoning behind why IMFs are involved with the examples they provided. Quotes from students that fell under the three categories shown in Figure 5.3 can be found in Tables 4.1 through 4.3 under CHAPTER 4 (Results).

This study did not specifically investigate the misconceptions present in students' understanding of the concept of IMFs, however the major misconception as stated in CHAPTER 4 (Results), was the confusion of intramolecular forces with intramolecular forces (IMFs). From the student interview transcripts and my experience with IMFs as an undergraduate student, students' confusion seems to stem from the language used. It was not until I heard a talk in graduate school about misconceptions relating to IMFs that I fully understood that the term "hydrogen bonding" was not the bond between a hydrogen atom and an oxygen atom in a water molecule, but the interaction between the slightly positive hydrogen end and the slightly negative end of two different water molecules. Language such as "like atoms, like being held together" (Phoebe CHEM 127, [18]), "how atoms like interact" (Djokovic, CHEM 326 [21]), "…[IMFs] are what keeps…the ions in a molecule…together…" (Mojisola, CHEM 114, [59]), "…if [the molecules] are more strongly held together, their boiling point is going to be higher because it has to have more energy…when you break the bond…" (Simona, CHEM 326, [37-38]), indicate the confusion between intramolecular and intermolecular forces of the students in this study. When I hear the term 'bond', I automatically think a bond between two atoms or ions, and so from a student's point of view, it is understandable that the term "hydrogen bond" is conceptualized as between atoms instead of a force between molecules. Even though this study did not focus on misconceptions, I think this point brings up a thought that instructors should consider – how are students receiving the language we as instructors are using to present information to them? Are we clear in our communications or are we confusing our students?

I would argue that one reason most of the student participants fell under the no/incorrect and partially correct explanations for transfer was because their foundational knowledge of the concept of IMFs was not fully correct – there were misconceptions present. Of the 39 participants, 28 of them were categorized under minimal and no recollection levels. This means that 28 of the student participants, even if they were able to correctly arrange the three molecules given, were unable to provide a correct rationale for arranging three molecules in order of increasing boiling point. The majority of student participants in this study had an idea of what IMFs were; however, the limited amount of information these students were able to recollect were either partially correct or incorrect, as evidenced by their abilities to define IMFs and provide a rationale for arranging the three molecules the way they did. Prior knowledge is necessary for transfer, [119-120] however, studies have shown that partially correct or incorrect prior knowledge can impede the learning process.[76, 78-80]

Going back to the results from the recollection data, a majority of the students were unable to provide an accurate rationale for correctly arranging the three molecules provided in order of increasing boiling points. If these students do not understand the reasoning behind one of the main ideas about IMFs that they were explicitly taught (both Drs. Mufasa and Pumbaa explained how IMFs affect physical properties of substances), it is a stretch to believe they would be able to explain correctly the reasoning behind ideas that were not explicitly taught to them.[105, 115] As a constructivist, I would expect that given enough time, students would be able to transfer knowledge and explain concepts that were not explicitly taught to them. However, I would argue that instructors would rather have students with high transfer abilities earlier in their academic career (freshman or sophomore) rather than later (junior, senior or graduate level). If students were taught early on in their freshman and/or sophomore years that the information they learn in a chemistry class relates to their daily lives and other classes outside chemistry, and were encouraged to look for these connections (to daily life and other classes) across all the classes they had to take, then more students would be able to make those connections sooner. This will ultimately improve the learning process because these students are being trained to think critically and think outside the box.

Transfer to classes outside chemistry

CHEM 127 (n=9) and CHEM 326 (n=15) students were asked to give examples of IMFs in classes outside of chemistry. Of the 24 students, half (12) of them were unable to identify a class outside of chemistry where IMFs could be used. Eight of the 12 students able to identify a class were also able to give an example from the class identified that related to IMFs. Figure 5.4 gives a breakdown of this information by class.

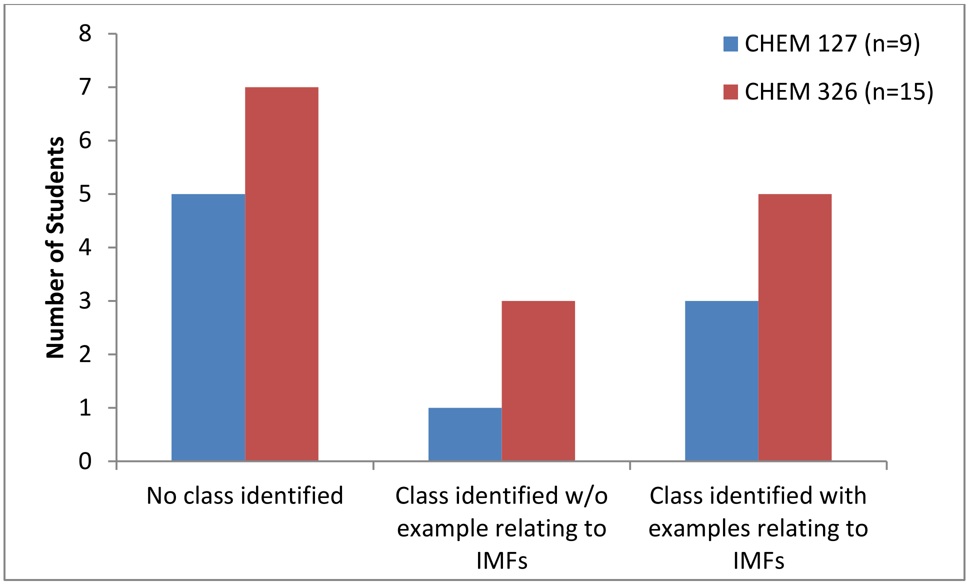


Figure 5.4. Students' abilities to transfer knowledge of IMFs to other classes.

The majority of the student participants (six (67%) from CHEM 127 and 10 (67%) from CHEM 326) were unable to identify a class outside of their chemistry class, or identified a class but could not provide an example relating to IMFs from that class. Figure 5.2 shows that the majority of the CHEM 127 and CHEM 326 student participants were able to provide examples of IMFs relating to their daily lives. However, very few of the same students were able to provide examples of IMFs from classes outside of chemistry (Figure 5.4). The reason behind this difference could be due to the emphasis placed by the professors (or not) on these two areas – daily life and other classes.

The professors that were interviewed all stated that topics in their chemistry courses were linked to other chemistry courses, and to courses outside of chemistry. Dr. Zazu, who teaches organic chemistry (CHEM 326), gave biochemistry and biology as examples of classes that relate to his class. Dr. Pumbaa, who teaches general chemistry (CHEM 115), stated that all the STEM fields are connected to general chemistry, while

Dr. Mufasa highlighted physics and economics. The concept of IMFs is important across all chemistry fields like organic, biochemistry and analytical chemistry. IMFs also show up in other disciplines – any discipline that involves molecules interacting with one another. Yet while Drs. Mufasa and Pumbaa acknowledged during their interviews that the specific course they taught tied in to several other courses, not once during my observations of their classrooms did they highlight another class where the concept of IMFs showed up. In his interview, Dr. Mufasa admitted that he did not emphasize the importance of connections between the specific chemistry course he teaches and other classes, but Dr. Pumbaa stated that it was important for students to make these connections between these different classes. According to Dr. Pumbaa, "…you would have to build connections to more applicable things in the fields, so that they have a better understanding of what's going on…" [21]

I did not observe Dr. Zazu's class, so I cannot comment on the emphasis he places on making connections between courses in the specific course he teaches. However, based on my observations in the classes of Drs. Pumbaa and Mufasa and their interviews, I can say that even though the intentions are good, they sometimes are not carried out. Understandably, there is a lot of material that professors are under pressure to cover, and so taking time to highlight certain classes that students will see certain material again may not be a priority for them. However, if the professors do not make a habit of emphasizing or reinforcing these connections to other classes, the majority of students are unlikely to make these connections by themselves.[105,115,119,160,162]

Figure 5.4 also shows that of the 24 CHEM 127 and CHEM 326 students, eight of them were able to give examples from a class outside chemistry that related to IMFs. Of these eight students, four provided no explanation or incorrect explanations about the example they provided, and three of them provided correct explanations. Figure 5.5 shows a breakdown by class of the eight students' abilities to provide explanations relating examples from other classes to IMFs, while Figure 5.6 shows the abilities of CHEM 127 and CHEM 326 students to provide explanations relating examples from their daily lives to IMFs.

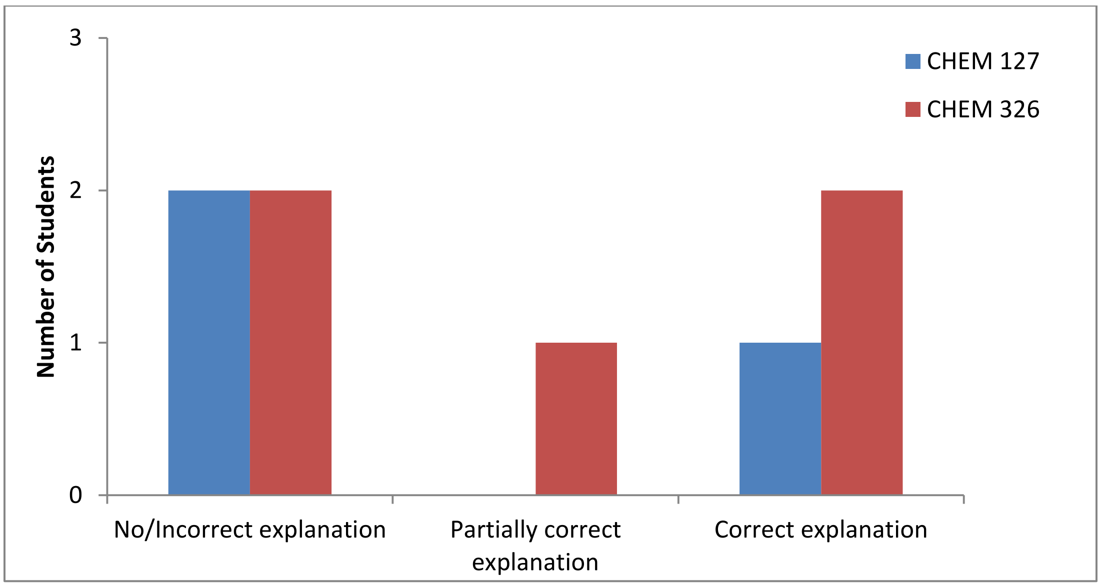


Figure 5.5. CHEM 127 and CHEM 326 students' abilities to provide explanations of how examples from other classes relates to IMFs.

The total number of CHEM 127 and CHEM 326 students that were able to give examples from their daily lives (Figure 5.6) was double the number of students who were able to give examples from classes outside chemistry (Figure 5.5), 16 to eight respectively. Three CHEM 127 students were able to give a correct explanation linking IMFs to their daily lives, while only one was able to give a correct explanation linking IMFs to a class outside chemistry.

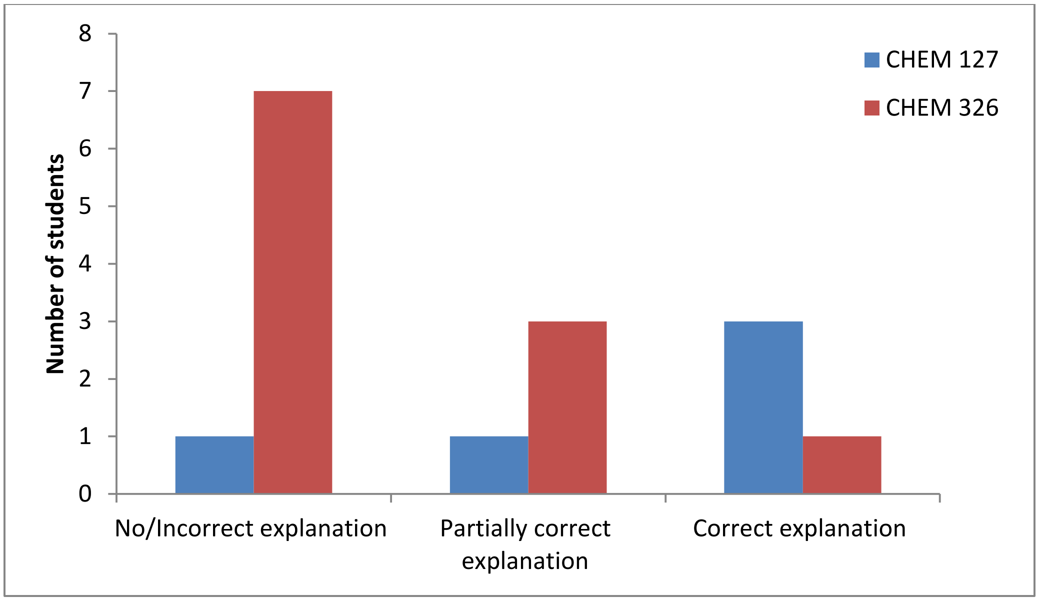


Figure 5.6. CHEM 127 and CHEM 326 students' abilities to provide explanations of how examples from their daily lives relates to IMFs.

In CHEM 326, one student was able to explain correctly the relationship between IMFs and their example from daily life, while two of them were able to link correctly IMFs to classes outside chemistry. The data collected for this study have shown that most of the student participants were only able to operate at the first level of Bloom's taxonomy in terms of recollection. For the students to be able to provide examples of classes outside chemistry where they see IMFs and explain correctly how IMFs tie into that class, they would have to go beyond just recalling information about a concept. Since the professors that were interviewed stated that they were not intentional about pointing out classes outside the current class where students will encounter IMFs, it is reasonable to expect that most of the student participants would not be able to provide classes outside chemistry. Furthermore, because the data showed that most of the student participants were operating at the first level of Bloom's taxonomy,[159] it is also reasonable to expect that most of the students would not be able to provide correct explanations, showing their understanding of the concept of IMFs.

A majority of the student participants were unable to provide explanations to link IMFs to their daily lives **and** to other classes correctly. However, Mordecai (CHEM 127) and Rafael (CHEM 326) were the two student participants who were able to do both. Below are excerpts from both interviews:

> Me: So can you give an example of IMFs outside of class…so in your everyday life for instance.
> Mordecai [38-41]: Uh, water beading up…because if there were no IMFs, [water] would just disperse, and since there are [IMFs], I see water droplets. Um, every time I go to cook rice or pasta, um, watching water slowly evaporate…if there were no IMFs, water wouldn't boil, and my rice would be crunchy…it [water] would all evaporate. There would be nothing keeping it as a liquid.
> Me: Have you seen IMFs in other classes outside chemistry?
> Mordecai [44]: Uh, biology. So like xylem in plants, I think that's the word, I haven't had bio in a long time, is the wall of plant uh, veins, I think they're called veins, something like that, but anyway, because water has those hydrogen bonds, it's able to cling to the sides, and you know, climb up to be used for photosynthesis

> Me: Um, can you give an example of IMFs, so intermolecular forces outside class? So in your daily life?
> Rafael [32-34]: Um, well gasoline boils, you know, really easily…has a really low boiling point because it only has van der Waals forces, so when you, you know, are putting gas into the car, you see it coming out, just because the temperature at which it boils is very low… . The energy required to break the bond between the two molecules is very low, so you don't have to add much heat

> to it…and then of course on the opposite end of the spectrum is water, where you have to add substantially more heat to break those bonds…
> Me: Have you seen IMFs in other classes outside chemistry?
> Rafael [61]: …I see IMFs' role particularly in BIOL 202 [genetics & cellular bio] when examining a molecule's partition coefficient, its ability to exist in a hydrophobic and hydrophilic environment. Molecules must be able to diffuse through both types of environments in order to enter a cell without using specific channels…this is not completely dependent on IMFs, size also plays a role, understanding the types of IMFs are necessary to predict the movement potential for a molecule."

Both Rafael and Mordecai gave examples that related to them. Mordecai talked about the IMFs in water being helpful for him to cook, while Rafael talked about gas evaporating as he pumps gas in his car. The interview transcripts suggest that Rafael and Mordecai have gone from just memorizing and remembering the concept of IMFs from class to actually understanding IMFs and being able to apply them to new situations (daily life and other classes). These students have gone past the remembering level of Bloom's taxonomy and are now operating at the understanding and application levels of Bloom's taxonomy.[159] These two students however, are exceptions to the typical first or second year chemistry student. Mordecai comes from a family of chemists, while Rafael, an older, non-traditional student, was returning to college with life experiences that shaped him as a student. As a result of their personal experiences, these two students were intrinsically motivated to go beyond just doing the homework and getting good grades. According to Rafael,

> "…I don't simply want to get like a good grade in the class, and I think it's very simple for most people to sort of learn and dump it immediately

> afterwards…whereas, I really want to understand everything about organic chemistry that I can, so I've tried to synthesize each concept into the next concept…I want to know more about [the class] than is even required, because I feel like that, going above and beyond helps me do better in the class." [41]

As I have been on both the student and instructor sides of the coin, I do know that the majority of students that take chemistry classes are not like Mordecai or Rafael. The majority of these students, especially at the freshman/sophomore levels, only want to take the class and move on to their major courses, and as seen in CHAPTER 4 (Results), the majority of the student participants in this study were indeed motivated because of their major/future career.

In summary, the data from this study show the following:

- The level of transfer, especially to other classes, for the majority of the student participants was very rudimentary,
- Professors do not explicitly discuss how their course content connects to other classes,
- The majority of student participants are motivated to learn chemistry because of their major/future careers.

In an ideal world, all the students would be like Mordecai and Rafael – driven to understand and apply the concepts taught, but we do not live in an ideal world. Nevertheless, I do believe it is possible to guide our students in ways that can take them from being purely extrinsically motivated to being intrinsically motivated to learn chemistry. If students come in motivated to learn chemistry because it relates to their major/future careers, as educators, we should capitalize on that and emphasize how those majors/future careers are connected to the concepts we teach in chemistry classes. When educators are able to facilitate transfer from the chemistry class to other classes that students see as being more relevant to their majors/future careers, then we might be able to spark more interest and excitement in students about how chemistry applies in their daily lives. One way to start this process is by encouraging discourse among STEM instructors that emphasizes the connections between the different classes. If the instructors are more aware of what the connections are among the classes, then it will be easier for them to communicate the connections to their students.

Effect of additional classes on transfer

The third sub-research question this study investigated was, "how do additional chemistry courses influence this transfer of knowledge?" Based on the results from this study, there is no straightforward answer to this question, as more variables (like different classes and high school chemistry background) would need to be explored. However, the level of reinforcement of a professor could play a role in the abilities of students to transfer knowledge from class to their daily lives. The more an individual consistently encounters an idea or concept, the higher the chances for that individual to internalize and transfer the idea or concept to other areas. [157-158]

According to the chemistry sequence at this university, CHEM 114 and CHEM 127 student participants would have taken CHEM 112 and CHEM 115 respectively at the college level. The sequence also dictates that CHEM 326 student participants would have taken two college level chemistry courses – CHEM 112 and CHEM 114. The difference between CHEM 326 students and CHEM 114 & CHEM 127 students is the extra chemistry class that CHEM 326 students have taken.

Going back to the abilities of students to transfer knowledge of IMFs to their daily lives, Figure 5.2 showed that most of the 39 student participants were able to give an example from their daily lives relating to IMFs. However, only three students from CHEM 127, one from CHEM 114 and one from CHEM 326 were able to provide a correct explanation of how these examples tie back to IMFs. In fact, compared to CHEM 114 and CHEM 127, more CHEM 326 students gave no or incorrect explanations linking IMFs to the example they gave from their daily lives (see Figure 5.3). These results are disconcerting because when asked, 10 of the 15 CHEM 326 student participants reported that they had an improved understanding of IMFs. So, what does it mean if these students believe their levels of understanding have improved, but are still unable to give a correct explanation of how IMFs are involved in boiling water? Studies[163-164] have shown that students generally have poor self-assessment abilities, as there is low correlation between their self-assessment and their performance, but does this ability change (positively or negatively) the more courses a student takes? Or did the student participants start their current class knowing absolutely nothing? In an ideal world, the more classes an individual takes in a particular subject, the more knowledgeable the individual becomes about that subject. CHEM 326 students may believe their chemistry knowledge improves as they take more chemistry courses, and this may be the case. However, if their initial knowledge (or lack of knowledge) is littered with misconceptions, then defining improvement in their knowledge becomes problematic, as their perceptions of improvement are likely skewed.

Table 5.2 shows the students who indicated they had seen IMFs in their current class and were able to give examples of topics from their class that involved IMFs, as well as their transfer to daily life and recollection abilities.

Of the 10 CHEM 326 students who stated they had improved understanding of IMFs in general (Table 5.2), five of them were categorized under total recollection, while the other five had minimal levels of recollection. Of the four CHEM 114 and CHEM 127 students, only one of them was categorized under total recollection; the other three had minimal levels of recollection. All the student participants who stated they had improved understanding of IMFs in general had some level of recollection. Since a pre-test was not carried out to determine what these students knew prior to entering their current class, we can assume they self-assessed themselves accurately as the data indicated they recollected some information about IMFs. However, it is somewhat disconcerting that a CHEM 326 student who believes their understanding of IMFs has improved cannot correctly arrange molecules in order of increasing boiling point and provide an accurate explanation for the arrangement.

Table 5.2. Students who indicated they had seen IMFs in their current class and their corresponding levels of transfer and recollection.

Student/Class	Improved understanding of IMFs in general	Improved understanding of IMFs application to daily life	Provided examples of IMFs from daily life	Level of transfer to daily life	Level of recollection
Mojisola 114	Yes	No	Yes	Minimal transfer	Minimal recollection
Deji 114	No	No	Yes	Moderate transfer	Total recollection
Tunde 114	Yes	Yes	Yes	Minimal transfer	Total recollection
Folake 114	No	No	Yes	Moderate transfer	Moderate recollection
Lara 114	Yes	Yes	Yes	Moderate transfer	Minimal recollection
Eve 127	Yes	Yes	Yes	Moderate transfer	Minimal recollection
Serena 326	Yes	Yes	Yes	Minimal transfer	Minimal recollection
Lleyton 326	Yes	Yes	Yes	Moderate transfer	Minimal recollection
Tsonga 326	Yes	No	Yes	Minimal transfer	Minimal recollection
Venus 326	Yes	No	Yes	Minimal transfer	Minimal recollection
Simona 326	Yes	Yes	No	No transfer	Total recollection
Djokovic 326	Yes	Yes	Yes	Minimal transfer	Minimal recollection
Gael 326	Yes	Yes	Yes	Moderate transfer	Total recollection
Agnieszka 326	Yes	No	No	No transfer	Total recollection
Petra 326	Yes	No	Yes	Minimal transfer	Total recollection
Rafael 326	Yes	Yes	Yes	Total transfer	Total recollection

It would be expected that an improved understanding of the applications of IMFs to daily life would correspond to higher levels of transfer to daily life. Table 5.3 shows students who stated their understanding of the applications of IMFs to their daily lives had improved and their corresponding levels of transfer.

Table 5.3. Students with self-reported improved understanding and corresponding transfer levels.

Student/Class	Improved understanding of IMFs applications to daily life	Provided examples of IMFs from daily life	Level of transfer to daily life
Tunde/114	Yes	Yes	Minimal transfer
Lara/ 114	Yes	Yes	Moderate transfer
Eve/ 127	Yes	Yes	Moderate transfer
Serena/326	Yes	Yes	Minimal transfer
Lleyton/326	Yes	Yes	Moderate transfer
Simona/326	Yes	No	No transfer
Djokovic/326	Yes	Yes	Minimal transfer
Gael/326	Yes	Yes	Moderate transfer
Rafael/326	Yes	Yes	Total transfer

Of the nine students who stated that they had improved understanding of the applications of IMFs to their daily lives, only one student (CHEM 326) was categorized under the total transfer level. One of the nine students was classified under the no transfer category. The other seven students who indicated they had improved their understanding of the applications of IMFs to their daily life were unable to articulate fully how IMFs apply to their daily lives but exhibited some level of transfer. Again, since a pre-test was not given to determine how these students applied IMFs to their daily lives prior to taking their current course, we can assume they self-assessed themselves accurately, with the exception of Simona (CHEM 326), who was categorized under the no transfer level. Simona was unable to provide an example from her daily life that related to IMFs. Her inability to provide an example of where IMFs could be found in her everyday life indicates that her understanding of the applications of IMFs to her daily life has not improved, as an individual with no understanding of the idea would also be unable to provide an example from their daily life.

Compared to the students who stated they had improved understanding of the applications of IMFs to their daily lives, more students stated they had improved understanding of IMFs in general (Table 5.2). I believe the reason there were more students who believed they had improved understanding of IMFs in general was because professors spent more time emphasizing the concept of IMFs, what they are and how they work, as opposed to specifically explaining how IMFs relate to daily life. During the interview process, when I asked both Drs. Mufasa and Pumbaa to give examples of where they would see IMFs in their daily lives, they both responded with examples – Dr. Pumbaa talked about drinking water, while Dr. Mufasa gave several examples, including coffee dissolving in water. Both professors were able to give examples of IMFs in their daily lives, but it was something they had to pause and think about. Furthermore, during my observations, the professors did provide real world examples but did not spend much time explaining how the IMFs played a role. If professors themselves do not spend much time thinking about how exactly IMFs influence daily activities, it is unlikely they would discuss it during a lecture. Again, the concept of reinforcement comes into play here. Students are more likely to pick up ideas that are constantly reinforced by the instructor, compared to ideas that are briefly mentioned or not mentioned at all.

In conclusion, the effect of additional classes on knowledge transfer is not an obvious one. Knowledge transfer is dynamic, however, it is also not just dependent on the instructor or the course, the learner also has a part to play in being able to transfer knowledge, just as the constructivist paradigm suggests. The data show that students do think about the knowledge they learn in terms of their everyday life, and this is likely because the instructor has pointed that out to them. However, these students do not generally think about the knowledge they learn in their chemistry class in terms of other classes because this is not something that is highlighted in their classes. In order for students to transfer knowledge from class to class, or from class to daily life, a conscious effort needs to be made by instructors (and ultimately the student) to highlight and reinforce these connections.

Recollection, transfer and attitudes

The fourth and final sub-research question this study investigated was "what is the relationship between recollection, transfer and students' attitudes towards chemistry?" To address this question, I decided to break the question down into three smaller questions:

- What relationship exists between ability to transfer knowledge and ability to recollect knowledge?
- What relationship exists between ability to recollect knowledge and attitude towards chemistry?
- What relationship exists between ability to transfer knowledge and attitude towards chemistry?

Relationship between ability to transfer and recollect knowledge

The general trend in this study was the lower the levels of recollection of the students, the lower their abilities to transfer knowledge, both to their daily lives and to other classes. Interestingly, most of the participants in this study, regardless of their levels of recollection, seemed to be able to transfer some knowledge about IMFs to their daily lives, while a majority of the students with minimal and no levels of recollection were unable to transfer any knowledge of IMFs to other classes.

The data collected in this study showed that students in CHEM 326 had higher levels of recollection compared to students in both CHEM 114 and CHEM 127, while students in CHEM 114 had lower levels of recollection compared to students in both CHEM 127 and CHEM 326. Furthermore, a majority of the CHEM 114 students fell under moderate and low levels of transfer to their daily lives, while a majority of the CHEM 326 students fell under low transfer and no transfer levels to their daily lives. In CHEM 127, most of the students had either high or low levels of transfer to their daily lives. Regarding levels of transfer to classes outside of chemistry, the results show that most of the CHEM 127 and CHEM 326 students were unable to transfer knowledge from their chemistry class to other classes.

The Tables 5.4 and 5.5 show recollection and transfer data for the student participants.

Table 5.4. Recollection and transfer to daily lives (CHEM 114, CHEM 127 and CHEM 326) n=39.

	High transfer	Moderate transfer	Minimal transfer	No apparent transfer
High recollection	3	2	2	2
Moderate recollection	0	1	1	0
Minimal recollection	2	5	8	7
No recollection	0	2	3	1

Table 5.5. Recollection and transfer to other classes (CHEM 127 and CHEM 326) n = 24

	High transfer	Moderate transfer	Minimal transfer	No apparent transfer
High recollection	3	0	2	2
Moderate recollection	0	0	1	0
Minimal recollection	0	1	1	12
No recollection	0	0	0	2

Table 5.4 shows that there are students with no recollection are still able to transfer knowledge of IMFs to their daily lives at the moderate and minimal levels. Interestingly, the five students who were able to transfer some knowledge of IMFs to their daily lives were students who had taken CHEM 112. As stated earlier, throughout my observations in CHEM 112, I noticed that Dr. Mufasa emphasized real world examples in his lectures. Furthermore, during my interview with Dr. Mufasa, he also stated that he thought it was very important for his students to make these connections to their daily lives. This again reinforces the idea that for students to learn, to transfer the knowledge that we as educators want them to transfer, we need to explicitly point out what we believe is important and also give them opportunities to be able to gain this knowledge. According to Johnson and Rutherford, "it is not enough that the connections between the material exist; students have to be able to perceive that the connections exist."[115]

Across all three classes (CHEM 114, CHEM 127 and CHEM 326), none of the students who fell under the no recollection level had a high level of transfer, but some of them exhibited some level of transfer (moderate or minimal) to their daily lives. On the other hand, Table 5.5 shows that none of the students who fell under the no recollection level were able to transfer knowledge of IMFs from their class to other classes outside of chemistry. These data show that students who have minimal or no levels of recollection have minimal or no transfer abilities to their daily lives and other classes.

The professors that were observed and interviewed in this study acknowledged that there were connections between the classes they taught and other classes, but none of them were explicit about emphasizing these connections. In light of this, it is expected that the student participants would have a more difficult time making connections between classes. According to Gallagher, “students are not commonly taught to, nor that they should, make connections between new information and that which they have previously learned…”[161] If the students are not taught to make these connections or taught how to make these connections, they will struggle to make them, as evidenced by the data in this study.

This study was designed as a qualitative study as evidenced by the research question, frameworks used, the sample size, the data collection and analysis. However, as the data analysis progressed, I thought it would be worthwhile to investigate whether there were certain statistical tests I could run on my data even with the small sample size. The majority of quantitative tests that measure the relationship between two or more variables are measured on a continuous scale (e.g. temperature, weight and blood pressure).[165] However, since the data in this study consisted of nominal variables (variables consisting of “a collection of sub-categories”[165]), I decided to use the chi-square test to investigate relationships between the variables in this study (recollection, transfer and attitudes). The chi-square test deals with nominal variables and compares observed values to expected values and determines whether the difference in these values is due to chance.[165] Appendix H shows an example of the way this test was carried out on the data from this study.

One main issue with conducting statistical analysis on the data in this study is the sample size. Tolmie et al.[165] suggest a sample size of between 150 and 200 to run statistical tests to ensure that the correlations observed from the results are not due to random errors or outliers in the data. The sample size for this study is well below the 150-200, which raises a major concern for statistical tests. In addition to the small sample size, an issue with the chi-square test is that if any of the frequencies on a table are less than or equal to one, Type I (rejecting the null hypothesis even though it is true) or Type II (failing to reject the null hypothesis even though it is false) errors may occur.[165] As seen in Tables 5.4 – 5.10 there are several cells with zeros or ones. With these main issues (sample size and cell frequencies or one and zero) from the data, I did not expect to get statistically significant results. The null hypothesis for the chi-square tests that were carried out was that one variable (e.g. recollection) did not influence the other variable (e.g. attitude). At the p=0.05 significance level, none of the tests carried out were statistically significant, which means the null hypothesis could not be rejected. Appendix H gives a full breakdown of the tests and the findings. These results (Appendix H) were not surprising because the study was not designed to be a quantitative study. However, from these numbers and the general trends observed in this study,

- Students with lower levels of recollection are less likely to transfer knowledge to new situations, i.e., their daily lives and other classes
- The emphasis placed on certain areas by professors can influence the levels of recollection and transfer.

Further studies should be carried out to investigate if these trends hold true across several other classes and regions. Nevertheless, based on these trends I would suggest that instructors begin to consciously make efforts not only to tie what they are teaching to students' daily lives but to other classes their students are likely to take. Steps should be taken by instructors to determine the majors of their students and the classes they have to take for those majors. If the instructors are able to emphasize the relationship between these courses, then maybe the students would be more apt to recollect and transfer more information both to their daily lives and to other classes.

Relationship between ability to recollect and attitude towards chemistry

The results from this study suggest a positive relationship between levels of recollection and student attitudes towards chemistry. Table 5.6 below shows the level of recollection of students and their corresponding attitudes, based on the scale shown in CHAPTER 2 (Literature Review).

Table 5.6. Level of recollection vs. attitude towards chemistry (n=39).

	High recollection	Moderate recollection	Minimal recollection	No recollection
Positive	6	2	9	1
Slightly positive	3	0	6	5
Neutral	0	0	3	0
Slightly negative	0	0	3	0
Negative	0	0	1	0

In general, most of the students in this study either had positive or slightly positive attitudes towards chemistry. Interestingly, the students who had neutral, slightly negative and negative attitudes towards chemistry were categorized under the minimal level of recollection. From the observations stated above, one would think that the relationship between a student's level of recollection and their attitude towards chemistry is that the more the student is able to recollect, the more positive their attitude will be towards chemistry.

In theory it makes sense that there is a positive relationship between attitudes and recollection, and the data in Table 5.6 does suggest this. However, Table 5.6 also shows that all six students who were categorized under the no recollection category either had positive or slightly positive attitudes towards chemistry. Of these six students, four of them were in CHEM 114, one in CHEM 127 and one in CHEM 326. Conversely, of the seven students with minimal levels of recollection, classified under neutral, slightly negative and negative attitudes, four were in CHEM 326, two in CHEM 114 and one in CHEM 127. To rephrase, most of the students who were unable to recollect any information about IMFs, but still had positive attitudes towards chemistry were CHEM 114 students, while most of the students who were able to recollect minimal information about IMFs, but did not have positive attitudes towards chemistry were CHEM 326 students. Several factors could have influenced this trend, including the difference in material taught in CHEM 114 compared to CHEM 326 and the emphasis placed by professors on connecting the material to ideas familiar to the students. The courses I enjoyed most as a student were those where I could relate the content to something else that I found interesting. As a student, I found general chemistry easier to relate to compared to organic chemistry, and as a teaching assistant, I found anecdotal evidence that suggest students also find general chemistry easier to relate to compared to organic chemistry. It is possible that even though these CHEM 114 students were unable to recollect information about IMFs specifically, the emphasis placed by their instructor on connecting concepts to their daily lives influenced their attitudes. Conversely, even though the CHEM 326 students vaguely remembered some information about IMFs, their inability to connect information from their class to other areas could have influenced their attitudes towards chemistry. Their frustrations with their inabilities to remember as much as they believe they should could be a reason for their negative attitudes towards chemistry. This idea of students' frustrations with being able to recollect only minimal information will be discussed further in this chapter.

A quantitative study investigating how much the levels of recollection of students influence their attitudes towards chemistry would be an interesting follow up to this study. This quantitative study could shed light on how much student attitudes towards chemistry relates to their levels of recollection. The data collected for this study suggest a positive relationship exists between levels of recollection and student attitudes towards chemistry. Further qualitative and quantitative studies should be carried out to investigate whether or not this trend holds true across different populations.

Relationship between ability to transfer and attitude towards chemistry

From the results of this study, the relationship between students' attitudes towards chemistry and their abilities to transfer knowledge of IMFs from their chemistry class to both their daily lives and to other classes is a positive one. Students with higher levels of transfer abilities had more positive attitudes towards chemistry, while students with lower levels of transfer had more neutral, slightly negative and negative attitudes.

Table 5.7 shows the relationship between student attitudes towards chemistry and their abilities to transfer knowledge to their daily lives, while Table 5.8 shows the relationship between student attitudes towards chemistry and their abilities to transfer knowledge to other classes.

Table 5.7. Level of transfer to everyday life vs. attitude towards chemistry (n=39).

	High transfer	Moderate transfer	Minimal transfer	No transfer
Positive	4	5	4	5
Slightly positive	1	4	6	3
Neutral	0	1	1	1
Slightly negative	0	0	2	1
Negative	0	0	1	0

Table 5.8. Level of transfer to other classes vs attitude towards chemistry (n=24).

	High transfer	Moderate transfer	Minimal transfer	No transfer
Positive	2	1	3	6
Slightly positive	1	0	1	5
Neutral	0	0	0	2
Slightly negative	0	0	0	3
Negative	0	0	0	0

Again, most of the students in this study have positive to slightly positive attitudes towards chemistry. From Table 5.8, all the students who had some level of transfer to other classes (high, moderate or minimal) had positive to slightly positive attitudes towards chemistry. On the other hand, even though most of the students who were unable to transfer any knowledge had positive or slightly positive attitudes towards chemistry, all the students who had neutral or slightly negative attitudes towards chemistry were unable to transfer knowledge of IMFs from their chemistry class to classes outside of chemistry.

The trend seen in Table 5.7 is also very similar to the trend seen in Table 5.8. Students with high levels of transfer to their daily lives had positive to slightly positive attitudes towards chemistry, and students with moderate levels of transfer had positive, slightly positive and neutral attitudes towards chemistry. Conversely, students who had slightly negative or negative attitudes towards chemistry fell under the minimal transfer or no transfer categories. These trends suggest a positive relationship between students' abilities to transfer information and their attitudes towards chemistry – the higher the student's ability to transfer knowledge, the more positive their attitude towards chemistry.

It should be noted that in this study, all the students who were able to transfer some knowledge of IMFs from their chemistry class to classes outside of chemistry reported either positive or slightly positive attitudes towards chemistry. This is interesting to me because as an instructor, I tend to focus more on helping students relate chemistry more to their daily lives. However, based on these results, it seems that relating chemistry to other classes might also be a way to get students excited about and engaged in the chemistry learning process. The professors in this study mostly focused on giving their students real world connections, and not connections to other classes. Another follow up study that can be done is investigating the effects of emphasizing connections between several courses on the attitudes of students towards chemistry.

Relationship between recollection, transfer and attitudes

The results from this study did not give a clear relationship between students' levels of recollection and their abilities to transfer knowledge to their daily lives; however, it was observed that students that had lower levels of recollection were less likely to transfer knowledge of IMFs to other classes. To investigate this relationship further, I sorted students based on their recollection and transfer abilities, and their corresponding attitudes. Table 5.9 shows the relationship between students' abilities to transfer knowledge to their daily lives and their levels of recollection, and their corresponding attitudes towards chemistry.

Table 5.9. Relationship between level of recollection of students, their level of transfer to daily life and their attitudes towards chemistry. (CHEM 114, CHEM 127 and CHEM 326; n= 39).

	Positive Attitude	Slightly Positive	Neutral Attitude	Slightly Negative	Negative Attitude
High recall/High transfer	3				
High recall/ Moderate transfer	1	1			
High recall/ Minimal transfer		2			
High recall/ No transfer	2				
Moderate recall/ High transfer					
Moderate recall/ Moderate transfer	1				
Moderate recall/ Minimal transfer	1				
Moderate recall/ No transfer					
Minimal recall/ High transfer	1	1			
Minimal recall/ Moderate transfer	3	1	1		
Minimal recall/ Minimal Transfer	2	2	1	2	1
Minimal recall/ No transfer	3	2	1	1	
No recall/ High transfer					
No recall/ Moderate transfer		2			
No recall/ Minimal transfer	1	2			
No recall/ No transfer		1			

Table 5.9 consists of data for all three classes, CHEM 114, CHEM 127 and CHEM 326. On the other hand, Table 5.10 shows the relationship between students' abilities to transfer knowledge to other classes outside chemistry and their levels of recollection, and their corresponding attitudes towards chemistry for CHEM 127 and CHEM 326 students.

Table 5.10. Relationship between level of recollection of students, their level of transfer to other classes and their attitudes towards chemistry. (CHEM 127 and CHEM 326; n=24).

	Positive Attitude	Slightly Positive attitude	Neutral Attitude	Slightly Negative Attitude	Negative Attitude
High recall/High transfer	2	1			
High recall/ Moderate transfer					
High recall/ Minimal transfer	2				
High recall/ No transfer	1	1			
Moderate recall/ High transfer					
Moderate recall/ Moderate transfer					
Moderate recall/ Minimal transfer	1				
Moderate recall/ No transfer					
Minimal recall/ High transfer					
Minimal recall/ Moderate transfer	1				
Minimal recall/ Minimal Transfer		1			
Minimal recall/ No transfer	5	2	2	3	
No recall/ High transfer					
No recall/ Moderate transfer					
No recall/ Minimal transfer					
No recall/ No transfer		2			

As stated in previous sections, the majority of the students that participated in this study had positive or slightly positive attitudes towards chemistry, regardless of their levels of transfer and ability to recollection information. Looking at Tables 5.9 and 5.10, the students with high to moderate levels of recollection, regardless of their levels of transfer, did not have neutral nor negative attitudes towards chemistry. In Table 5.9, of the 12 students (31% of the 39 total students) who fell under the high to moderate levels of recollection, five of them were CHEM 326 students, four were CHEM 114 students and three were CHEM 127 students. In Table 5.10, of the eight students (33% of the 24 total students) who fell under the high to moderate levels of recollection, five were CHEM 326 students, while the other three were CHEM 127 students.

Interestingly, regardless of their levels of transfer, none of the students who fell under the no recollection category had neutral or negative attitudes towards chemistry. In Table 5.9, of the six students (15% of the 39 total students) who fell under this category, four of them were from CHEM 114, one from CHEM 127 and one from CHEM 326. In Table 5.10, of the two students (8% of the 24 total students) that fell under the no transfer category, one was from CHEM 127 and the other was from CHEM 326.

Based on these data, it seems that the attitude of students who are taking higher chemistry classes is influenced more by their ability to remember what they have been taught in previous classes compared to students in lower chemistry classes. Evidently, attitudes can be influenced by several different factors,[1-14] and students' abilities to recollect information could also be a factor that influences attitude, but at the lower class levels, based on the results from this study, recollection of previously taught information does not seem to influence attitudes as much. From the data obtained in this study, this result is not strange, as several students in CHEM 114 and some in CHEM 127 mentioned that they enjoyed chemistry because it was similar to mathematics. At the higher levels, when the chemistry progressively goes beyond just the stoichiometry and students' abilities to plug in numbers correctly into an equation, it seems the attitudes of students then become more centered on what they actually know about chemistry, and not just the enjoyment they derive from working through an equation and getting the correct answer.

In Table 5.9, of the 39 students that participated in the study, three of them had neutral attitudes towards chemistry, three also had slightly negative attitudes towards chemistry, and one had a negative attitude towards chemistry. All of these seven students (18% of the 39 students) fell under the minimal level of recollection, with moderate levels of transfer, minimal levels of transfer, or no transfer to their daily lives at all. Four of these students were from CHEM 326, two were from CHEM 114 and one from CHEM 127. In Table 5.10, of the 24 students, two students had neutral attitudes towards chemistry, while three had slightly negative attitudes towards chemistry. Interestingly, all five of these students also fell under the minimal recollection and no transfer to other classes category, and four of them were from CHEM 326, while one was from CHEM 127. I noticed that the minimal level of recollection was the thread that tied the students with neutral and negative attitudes together, and as mentioned earlier, there could be frustrations attached to the students' inability to remember as much as they believe they should remember. I decided to dig deeper into the interview transcripts of these students to see if there were similar statements/themes that appeared throughout these transcripts that possibly showed their frustrations with their learning processes.

A theme that was common to these seven students (the five students from Table 5.10 were part of the seven from Table 5.9) was that they learnt just enough information to get them through the class. According to Feyi (CHEM 114 – minimal recollection, negative attitude), "I feel like I can grasp just enough of it to get through the test and through the work, but I'm not really, really understanding it that well. [15]" From their interviews, these seven students were able to get just what they needed to pass the class and move on to the next thing. They view chemistry as an unwanted and unnecessary bump in their otherwise smooth road to their ultimate career goal. A reason for these students' neutral/negative attitudes towards chemistry could be due to their frustrations with not understanding fully the concepts they are learning. Tsonga (CHEM 326 – minimal recollection, slightly negative attitude) states that "…if I probably understood the concepts better and it was just like, it clicked better, I probably wouldn't hate it as much. [71]" These students categorized under minimal recollection are different from the other levels of recollection because these students know that they remember something about the concept, but are frustrated because they know they do not fully understand the concepts.

Most of the students with neutral or negative attitudes were from CHEM 326, and were students with minimal levels of recollection, with varying levels of transfer to their daily lives, but no transfer to other classes. Based on the participants in this study, especially in the higher chemistry class, compared to students who are able to transfer information, students who are just able to recollect information and are not able to transfer that information to their daily lives, or to other classes, tend to have more negative attitudes towards chemistry. Looking at CHEM 326 for instance, students generally find organic chemistry difficult, and from this study, organic chemistry students who are unable to transfer the information they learn to classes outside their chemistry class have more negative attitudes towards chemistry, when compared to those who are able to transfer some of the information to other classes. This could be because these students view the course (CHEM 326) as a waste of time because in their eyes, it does not relate to their major/field/career.

Chapter Summary

In summary:

- The majority of the student participants were able to recall basic knowledge about IMFs by providing the correct definition of IMFs and giving examples of IMFs from class.
- The majority of the students were able to provide examples of IMFs from their daily lives without giving correct explanations tying the example to IMFs, showing minimal transfer to daily life, while the majority of the students were unable to transfer knowledge of IMFs to classes outside chemistry.
- The effect of additional classes on students' abilities to transfer knowledge was unclear based on the data from this study.
- The data suggest:
    - A positive relationship between levels of recollection and transfer abilities
    - A positive relationship between levels of recollection and student attitudes towards chemistry
    - A positive relationship between transfer abilities and student attitudes towards chemistry.

The next and final chapter will highlight the main findings in this study and address the research question. Suggestions for improved teaching strategies will also be discussed.

CHAPTER 6: ASSERTIONS, IMPLICATIONS AND RECOMMENDATIONS

The overall goal of this project was to answer the question "how do students' abilities to recollect information about intermolecular forces (IMFs) and transfer that knowledge of IMFs from class to class, as well as their everyday lives, influence their attitudes towards chemistry?" The following are key findings from this study:

- The data suggest a positive relationship between students' abilities to recollect information and their abilities to transfer that information, between levels of recollection and student attitudes towards chemistry, as well as between students' abilities to transfer knowledge and their attitudes towards chemistry.
    - The majority of the student participants were able to remember very basic information about IMFs (definition of IMFs and types of IMFs) from their previous class.
    - The majority of the student participants were able to give examples of IMFs from their daily lives, but unable to explain how IMFs related to the example they gave, showing very limited transfer of the knowledge of IMFs to their daily lives.
    - Very few of the student participants were able to provide an example of IMFs from a class outside of chemistry, indicating that the majority of the student participants were unable to transfer knowledge of IMFs to classes outside of chemistry.

- The level of reinforcement of material by the professor could play a role in influencing the level of recollection and knowledge transfer of the students.

So, based on these findings, the following assertions can be made about the overall research question:

- Students' abilities to recollect information they have learnt previously is very low, and this low level of recollection corresponds to low abilities to transfer knowledge to their daily lives and to other classes.
- Students with lower levels of recollection and transfer have less positive attitudes towards chemistry, suggesting that the abilities of the students to recollect and transfer knowledge can influence their attitudes towards chemistry.

Implications and Recommendations

As a student as well as an instructor, this study has been eye opening on several levels. While this study did not seek to investigate a causal relationship among recollection, transfer and student attitudes, it has highlighted relationships between the three variables as well as other possible factors that may influence these variables. One factor could be the students' motivation to learn chemistry, a factor that is tied to attitudes. The majority of the students in this study indicated that their motivation to learn chemistry was based on their major/future career. As an instructor, if I recognize that many of my students are motivated to learn chemistry because they believe it is pertinent to their future, then I will focus more on emphasizing how certain concepts apply to other classes and other fields outside chemistry. This emphasis could improve students' attitudes towards chemistry. Furthermore, the majority of the students recognized that chemistry was relevant to their daily lives, and so in addition to emphasizing how concepts in chemistry relate to other classes and majors, emphasis on how these concepts relate to students' daily lives could improve attitudes.

This study has also highlighted the role instructors can play in facilitating knowledge transfer. The students' ability to transfer knowledge is an important part of their education, and reinforcement by the instructors can play a role in facilitating more students transfer abilities. Again, as an instructor, recognizing that the emphasis I place on certain areas as I teach can help facilitate knowledge transfer in my students, I will be more conscious about pointing out areas that I believe are important for my students to take to other classes, and ultimately their future careers.

The data collected and the results from this study addressed the questions I posed, however, I am leaving this study with even more questions that I would like to investigate. The following are my recommendations for future work based on this study:

- The chemistry concept investigated in this study was IMFs, however, as there are other core concepts in chemistry, studies investigating these other areas should be carried out.
- Further studies should be carried out to investigate the relationship between the three variables (recollection, transfer and attitudes) in other populations using IMFs and other concepts to see if the findings from this study hold true when carried out in other populations.
- The relationship between the three variables discussed in this study should be investigated in other STEM fields outside chemistry.

- Quantitative studies should be carried out to determine the level of correlation among these three variables.

Finally, an immediate follow up study that I would like to carry out would involve a pre/post-test determining the initial attitudes of students towards chemistry before they begin a class, and their attitudes after going through a chemistry class where the teacher focuses on emphasizing relationships between the chemistry concepts and classes outside the chemistry class. A study like this would be instrumental in determining the role emphasis on certain ideas by a professor plays on the attitudes of students, and the abilities of students to transfer knowledge to other classes.

Recommendations for Instructors

The findings in this study can useful in improving the teaching and learning process. The following are my recommendations for instructors:

- I believe dialogue among STEM instructors should be highly encouraged. For instance, as a general chemistry instructor, I would be looking to have conversations with instructors who teach both the first and second semester of physics, biology and engineering courses, as well as instructors who teach organic chemistry, analytical chemistry, physical chemistry, biochemistry and inorganic chemistry. The conversations would revolve around the following questions:
    - What are you expecting general chemistry to teach your students to be successful in your class?
    - What are areas of general chemistry that you believe connect to the class(es) you teach?

I believe these types of conversations are necessary for instructors to understand how to prepare their students for the future classes they need to take.

- In addition to these dialogues, I do think it is necessary for instructors to be intentional about emphasizing the importance of these connections to their students. As a student, if an instructor keeps telling me that a certain idea connects to a class I am looking forward to taking, then I will be more likely to pay attention to that concept and remember it when I get to that class.
- Finally, I believe it is very important for the instructor to know their students. If as an instructor I am having dialogues with only physics, biology and engineering instructors, trying to understand what they need their students to know, but most of the students in my general chemistry class are nursing majors or exercise science majors, then I am doing them a disservice by not reaching out to the instructors that teach these majors. I have been a teaching assistant (TA) for a little over five years, and one of the things I have learnt is that no class is ever the same, and so it is important to tailor every class I teach to the students in the specific class.

Final Thoughts

As I stated earlier, no two classes will ever be the same, however, there will likely be similarities. A lot of information has been presented in this dissertation, which is specific to the participants of this study. However, I do hope that from this qualitative study the reader is able to find ideas that can be applied to their specific population and more ways to answer questions regarding recollection, transfer and student attitudes towards chemistry.

Limitations of the study

Guba and Lincoln state that a generalization is essentially "…an assertion that is context free… [however] *it is virtually impossible to imagine any human behavior that is not heavily mediated by the context in which it occurs*."[165] The context of this study, including the setting, background and population are not representative of all chemistry students and faculty members across the face of the earth. However, enough details on how the participants were selected, the data collection process, and the data analysis process have been provided so that the assertions stated in this chapter can be used as deemed appropriate by other researchers carrying out similar studies.

APPENDIX A

South Dakota State University

SDSU™

Office of Research/Human Subjects Committee
SAD Room 124
Box 2201 SDSU
Brookings, SD 57007

To: Oluwatobi Odeleye, Department of Chemistry & Biochemistry

Date: June 25, 2014

Project Title: How do students' abilities to transfer knowledge from a chemistry class to their daily lives influence their attitudes towards chemistry?

Approval #: IRB-1406007-EXM

Thank you for taking such care in completion of the request and research protocol. This project is approved as exempt human subjects' research. The basis for your exempt status from 45 CFR 46.101 (b) is:

(2) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior, unless:
(i) information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; and (ii) any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, or reputation;

If there are any unanticipated problems involving risks to subjects or others, or changes in the procedures during the study, contact the SDSU Research Compliance Coordinator. Protocol changes must be approved by SDSU prior to implementation. At the end of the project please inform the committee that your project is complete.

If I can be of any further assistance, don't hesitate to let me know.

Sincerely,
Norm

Norman O. Braaten
SDSU Research Compliance Coordinator

APPENDIX B

South Dakota State University

SDSU™

Office of Research/Human Subjects Committee
SAD Room 200
Box 2201 SDSU
Brookings, SD 57007

To: Oluwatobi Odeleye, Department of Chemistry & Biochemistry

Date: May 12, 2015

Project Title: What are some teaching strategies used by professors teaching freshman and sophomore level chemistry courses to facilitate transfer of knowledge between classes, as well as from class to students' daily lives?

Approval #: IRB-1505004-EXM

Thank you for taking such care in completion of the request and research protocol. This project is approved as exempt human subjects' research. The basis for your exempt status from 45 CFR 46.101 (b) is:

(2) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior, unless:
(i) information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; and (ii) any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, or reputation;

If there are any unanticipated problems involving risks to subjects or others, or changes in the procedures during the study, contact the SDSU Research Compliance Coordinator. Protocol changes must be approved by SDSU prior to implementation. At the end of the project please inform the committee that your project is complete.

If I can be of any further assistance, don't hesitate to let me know.

Sincerely,
Norm

Norman O. Braaten
SDSU Research Compliance Coordinator

APPENDIX C

Observation Protocol for General Chemistry I (CHEM 112) and General Chemistry for majors (CHEM 115)

- How is the concept of intermolecular forces (IMFs) being taught? (e.g. lecture, active learning, hands-on experiments, etc.)
- Does the teacher link the topics to the real world? If so, how?
- How much time does the teacher spend on the topic?
- Does the teacher view the topic as being important? Is it a must (in the teacher's opinion) for the students to understand IMFs to be successful in the field of chemistry?
- What kinds of examples are given in relation to IMFs? Are these examples of interest to the students? Are the examples memorable? Do they stick with the students?

APPENDIX D

<u>Interview protocol for CHEM 112 and CHEM 115 professors</u>

- How long have you been teaching CHEM 112/CHEM 115 at this university?
- Have you taught on the topic of IMFs every time you have taught CHEM 112/CHEM 115?
    - Why? / Why not?
- Do you think it is important for students to grasp the concept of IMFs well in CHEM 112/CHEM 115?
    - Why? / Why not?
- What does the term "intermolecular forces" mean to you?
- Can you give a few examples of where you see IMFs at work in your daily life?

APPENDIX E

Survey questions

- What is your major?
    - Options: Science, Engineering, Pre-professional, Dietetics, Exercise Science, Other
- What is your year of study?
    - Freshman
    - Sophomore
    - Junior
    - Senior
    - Other
- Why are you taking this chemistry class?
    - To fulfill a graduation requirement
    - To fulfill a major requirement
    - It is an elective
    - Because I enjoy chemistry
    - Other
- Statement: I like chemistry very much:
    - Strongly Agree
    - Agree
    - Neutral
    - Disagree
    - Strongly Disagree
- Statement: I like CHEM114/127/326:
    - Strongly Agree
    - Agree
    - Neutral
    - Disagree
    - Strongly Disagree
- Statement: I think chemistry is not relevant to my life:
    - Strongly Agree
    - Agree
    - Neutral
    - Disagree
    - Strongly Disagree

APPENDIX F

Students Interview Questions

- How are students able to transfer what they have learnt about IMFs in General Chemistry I (CHEM 112 and CHEM 115) to their daily lives?
    - What does the term "intermolecular forces" mean to you?
        - What do you remember about this term?
    - Can you give examples of IMFs from class that was meaningful to you?
        - Can you arrange these molecules in order of increasing boiling points? CCl_4, F_2, and H_2O. Please explain your thought process.
    - Can you give an example of IMFs outside class – in your daily life? Other classes?
- How do additional chemistry courses influence this transfer of the IMFs concept to their daily lives?
    - Have you learnt anything new about IMFs in your present class? Please provide an example.
    - Did what you learn help improve your understanding of IMFs? How?
    - Based on the responses to the question above, has your understanding of the application of IMFs to your everyday life changed? How?
- What is the relationship between the ability to transfer this knowledge and their attitude towards chemistry?
    - How would you describe your overall attitude towards chemistry?
        - Do you feel like you are motivated to learn chemistry? Why/why not?
    - Do you believe that a better understanding of the course material affects your attitude towards chemistry? How/why?

APPENDIX G

Interview protocol for faculty participants

- How long have you been teaching chemistry to college students?
- How long have you taught here at South Dakota State University (SDSU)?
- Tell me a little about your teaching philosophy. What are your core/foundational beliefs about teaching?
- What courses do you routinely teach here at SDSU?
- Do you believe there are connections between chemistry courses? Why? / Why not?
- In the specific chemistry course(s) you teach, which other classes (both chemistry and non-chemistry) do you believe connect to the course(s)?
    - Do you think those connections are important? Why? / Why not?
- In the course(s) you routinely teach, do you emphasize the importance of making connections between other classes?
    - Why/Why not?
    - How do you do this?
- What does knowledge transfer mean to you?
    - Do you believe this is an important aspect of students' learning? Why? / Why not?
- What are some techniques you use to facilitate knowledge transfer from class to class in your students?
    - How effective do you think these techniques are?
    - How would/do you measure the effectiveness of your techniques?
- Do you think it is important for students to make connections between what is being taught in class and what goes on in their daily lives?
    - Why? / Why not?
- How do you help your students make connections between what they learn in class and their daily lives?
    - How effective do you think these techniques are? Why?

APPENDIX H

Chi-square Test

I conducted the chi-square test on the data from Tables 5.4-5.8 in Chapter 5 (Cross analysis). To manually calculate the chi-square statistic, the following formula is used:

$$\sum \frac{(O-E)^2}{E}$$

Where,

O = observed frequency (i.e. actual numbers from data)

E = expected frequency

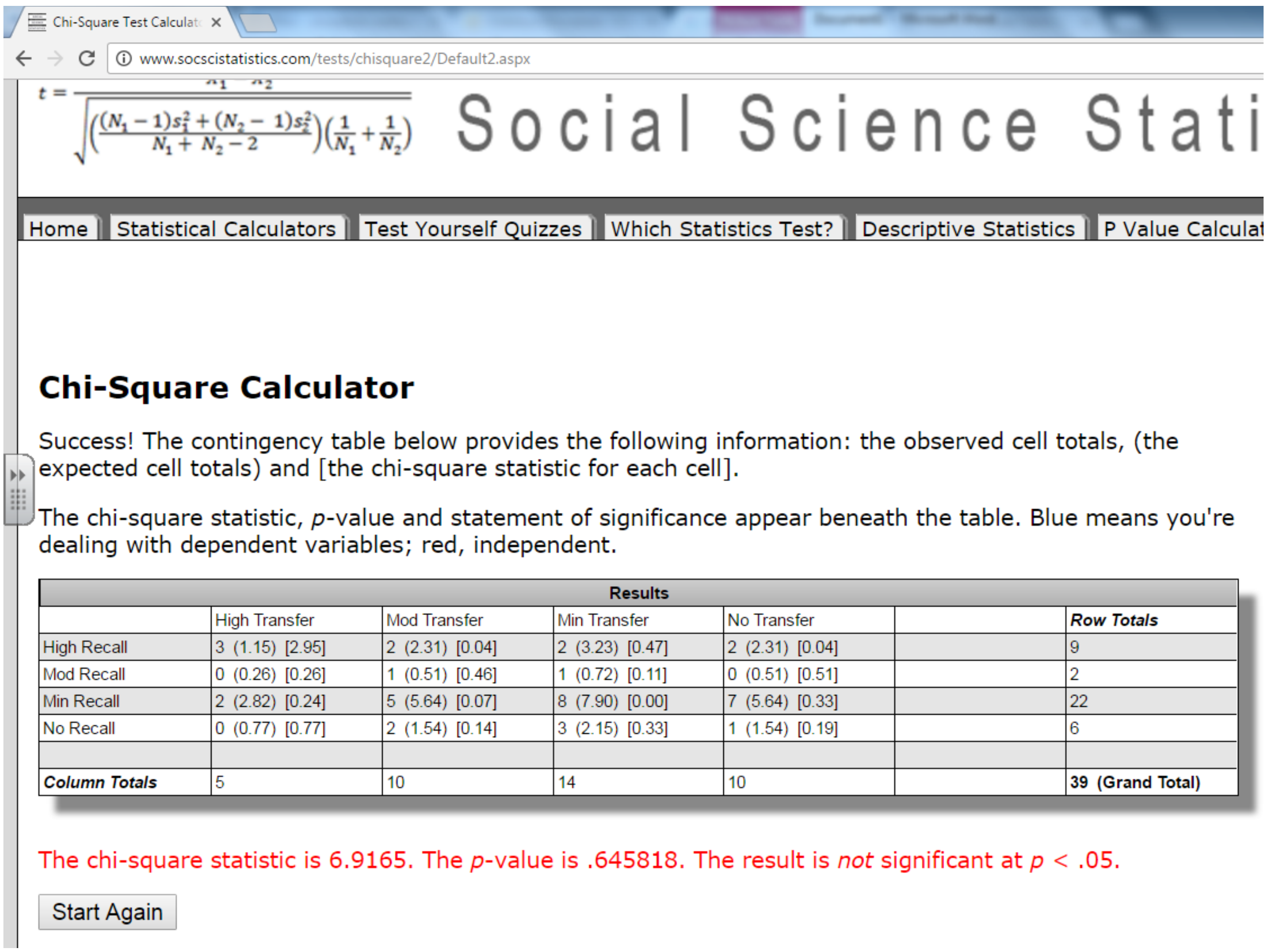
Once the chi-square statistic is found, the degrees of freedom must also be calculated using the following formula:

Degrees of freedom = (# of rows -1)(# of columns -1)

If the chi-square statistic is solved for manually, then the using the degrees of freedom and a chi-square distribution table the probability associated with the chi-square statistic can be found. This number will determine whether we can reject or accept the null hypothesis.[165] The null hypotheses that were tested were:

- There is no relationship between recollection and transfer (Figures 5.4 and 5.5)
- There is no relationship between attitude and recollection (Figure 5.6)
- There is no relationship between attitude and transfer (Figures 5.7 and 5.8)

I used a chi-square test calculator to calculate the chi square statistic and determine whether to reject or accept the null hypothesis (http://www.socscistatistics.com/tests/chisquare2/Default2.aspx). Figure A.1 shows the output for the data from Table 5.4. The p value that was used was 0.05, and the null hypothesis was that there was no relationship between students' levels of recollection of knowledge and their abilities to transfer that knowledge to their daily lives. The results in Figure A.1 showed that the null hypothesis could not be rejected, and this was the case for all the tests that were run.



Chi-Square Test Calculat

www.socscistatistics.com/tests/chisquare2/Default2.aspx

Social Science Stati

Home | Statistical Calculators | Test Yourself Quizzes | Which Statistics Test? | Descriptive Statistics | P Value Calculat

Chi-Square Calculator

Success! The contingency table below provides the following information: the observed cell totals, (the expected cell totals) and [the chi-square statistic for each cell].

The chi-square statistic, *p*-value and statement of significance appear beneath the table. Blue means you're dealing with dependent variables; red, independent.

Results						
	High Transfer	Mod Transfer	Min Transfer	No Transfer		***Row Totals***
High Recall	3 (1.15) [2.95]	2 (2.31) [0.04]	2 (3.23) [0.47]	2 (2.31) [0.04]		9
Mod Recall	0 (0.26) [0.26]	1 (0.51) [0.46]	1 (0.72) [0.11]	0 (0.51) [0.51]		2
Min Recall	2 (2.82) [0.24]	5 (5.64) [0.07]	8 (7.90) [0.00]	7 (5.64) [0.33]		22
No Recall	0 (0.77) [0.77]	2 (1.54) [0.14]	3 (2.15) [0.33]	1 (1.54) [0.19]		6
Column Totals	5	10	14	10		**39 (Grand Total)**

The chi-square statistic is 6.9165. The *p*-value is .645818. The result is *not* significant at *p* < .05.

Start Again

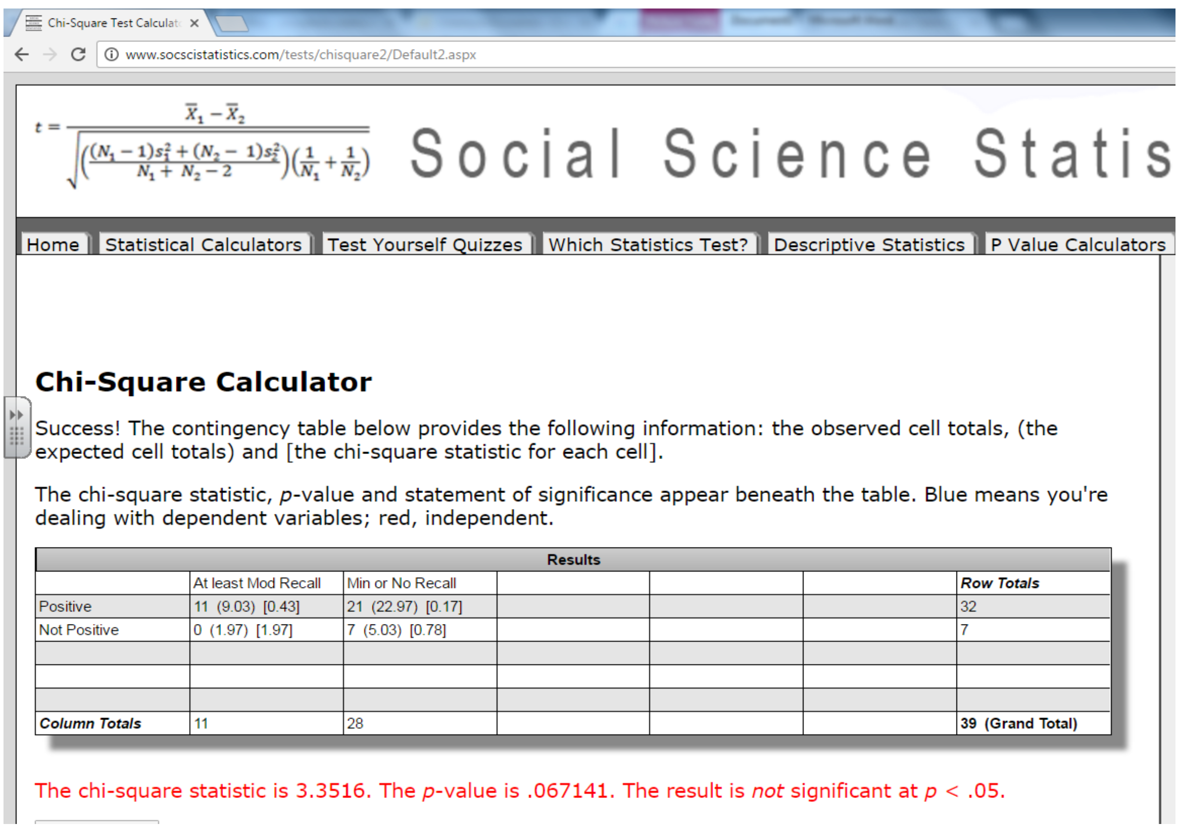
Figure A.1. Data from chi-square calculator for Table 5.4

After running the tests using all the cells in Tables 5.4-5.8, and accepting all the null hypotheses, since there were many cells with zeros and ones (explained in Chapter 5

(Cross Analysis)) I decided to collapse the tables to see if the statistics from the collapsed tables would be different. I collapsed the tables in these ways:

- I combined high & moderate transfer and high & moderate recollection
- I combined all transfer levels (high, moderate and minimal) and all recollection levels.
- I also combined attitudes as positive and not positive.

Even with the collapsed tables, the null hypotheses were still not rejected. Figure A.2 shows the results from the data in Figure 5.6, where the null hypothesis is that there is no relationship between levels of recollection and student attitudes towards chemistry.



Chi-Square Calculator

Success! The contingency table below provides the following information: the observed cell totals, (the expected cell totals) and [the chi-square statistic for each cell].

The chi-square statistic, *p*-value and statement of significance appear beneath the table. Blue means you're dealing with dependent variables; red, independent.

Results						
	At least Mod Recall	Min or No Recall				***Row Totals***
Positive	11 (9.03) [0.43]	21 (22.97) [0.17]				32
Not Positive	0 (1.97) [1.97]	7 (5.03) [0.78]				7
Column Totals	11	28				**39 (Grand Total)**

The chi-square statistic is 3.3516. The *p*-value is .067141. The result is *not* significant at $p < .05$.

Figure A.2. Data from chi-square calculator for Table 5.6

APPENDIX I

JOURNAL MANUSCRIPT

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CURRICULUM VITAE

Oluwatobi O. Odeleye

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Overview:

I am a passionate and energetic individual who loves the sciences. I enjoy teaching and I have taught several chemistry labs at the undergraduate level. My research interests revolve around students' attitudes towards chemistry, factors that influence those attitudes, and how educators can help bolster student interests towards chemistry specifically, but also science in general.

Education:

- PhD candidate in Chemistry, focus Chemistry Education, SDSU, Brookings, SD 57007, 2013- present. Advisor: Dr. Matt Miller
- M. S. in Chemistry, Eastern Michigan University (EMU), Ypsilanti, MI 48197, 2011-2013. Advisor: Dr. Amy Flanagan-Johnson
- B.S. in Chemistry, EMU, Ypsilanti, MI 48197, 2009-2011

Experience:

Research

- Exploring the relationship between students' abilities to recollect and transfer information and their attitudes towards chemistry (SDSU, with Dr. Matt Miller, current research project).
  - Used surveys, interviews and observations to address research question.
  - Qualitative based project involving transcribing, but also basic statistics to analyze survey data.
- Investigating the relationship between students' definitions of chemistry and their attitudes towards the discipline (EMU, with Dr. Amy Flanagan-Johnson, 2011-2013).
  - Used open-ended surveys and interviews to address research question.
  - Exposed to transcribing and data analysis for qualitative data sets.
- Working on selecting an aptamer for ATP using capillary electrophoresis (EMU, under Dr. Jeff Guthrie, 2011).
  - Used PCR and gel electrophoresis extensively and also worked with quantum dots.

Teaching

- First Semester General Chemistry Laboratory, SDSU, 2014-2016

  - Responsible for instruction and grading for 3 lab sections
- Chemistry Instruction in Higher Education, SDSU, 2014-2015
  - This course focused on equipping new graduate teaching assistants with skills to help them succeed as new teachers.
  - Co-taught this class with Dr. Matt Miller and focused on using different pedagogical approaches during the class to engage the students and show them how different teaching approaches could be used in their classes.
- Second Semester General Chemistry Laboratory, SDSU, 2014
  - Responsible for instruction and grading for 3 lab sections
- First Semester General Chemistry Laboratory for Honors' students, SDSU, 2013-2014
  - Assisted in designing some labs and developed grading rubrics for the labs.
  - Responsible for the instruction and grading for 3 lab sections
- Chemistry for Elementary Teachers Laboratory, EMU, 2011-2013
  - Assisted professor in teaching and grading labs .
- Organic Chemistry and Biochemistry Laboratory for non-majors, EMU, 2011-2012
  - Assisted professor in teaching and grading labs.

Outreach activities

- EmBe Girl's Maker Day, Sioux Falls, SD, October 2016
  - Had a booth with several hands-on activities, and about 100 girls from ages 8 – 14 were able to participate.
- Graduate Research Assistant, SDSU, 2016 – present
  - My role as a GRA includes:
    - Enhancement of community awareness of Biotechnology through the creation of grade 6-12 teacher professional development and student outreach programs.
    - Working with Sanford PROMISE, SD Biotech and SD EPSCoR to establish workshops and community tours to enhance STEM education and industry-education partnerships throughout the state of South Dakota.

Professional service activities

- Coordinated formation of the 'Chemistry and Biochemistry Association of Graduate Students' at SDSU (2016).
- Organized committee at SDSU to apply for the American Chemical Society Graduate Student Symposium Planning Committee (2014).
- Co-hosted the following symposia:
  - "A day in the life of my classroom" at the Biennial Conference on Chemical Education, Greeley, CO. August 2016.
  - "Chemical Education Research: Project Design and Data Collection Techniques" at the Biennial Chemical Education, Greeley, CO. August 2016.

  - "Chemical Education Research: Project Design and Data Collection Techniques" at the Biennial Chemical Education, Grand Valley, MI. August 2014.

Posters/Presentations

- Odeleye, O. O. *The relationship between students' attitudes and their abilities to transfer knowledge about intermolecular forces.* Paper presented at Biennial Conference on Chemical Education. Greeley, CO. August 2016.
- Odeleye, O. O. *AEOP eCybermission.* Presentation at the STEMwise Building Communities workshop, Sioux Falls, SD. July 2016.
- Odeleye, O. O., and Johnson, A.F. *"I don't like chemistry because..." How do students' definitions of chemistry influence their attitudes towards the discipline?* Paper presented at Biennial Conference on Chemical Education. Allendale, MI. August 2014
- Odeleye, O. O., and Johnson, A.F. *"School chemistry vs. real chemistry: An investigation of students' definitions and views of chemistry"* Paper presented at the 246th American Chemical Society National Meeting. Indianapolis, IN. March, 2013.
- Odeleye, O. O., and Johnson, A. F. "*The relationship between students' definition of chemistry and their attitude towards the discipline"* Paper presented at Eastern Michigan University's Graduate Research Fair. Ypsilanti, MI. March, 2013
- Odeleye, O. O., and Johnson, A.F. *"Factors that influence students' attitudes towards chemistry"* Paper presented at the Central Region of the American Chemical Society. Dearborn, MI. June, 2012.
- Guthrie, J. W., and Odeleye, O. O. *"Selection of aptamers for small molecules using quantum dots and capillary electrophoresis."* Paper presented at The Pittsburg Conference. Atlanta, GA. March, 2011.
- Odeleye, O. O., and Guthrie, J. W. *"Selection of an aptamer for ATP using capillary electrophoresis"* Poster presented at Eastern Michigan University's Undergraduate Symposium. Ypsilanti, MI. February, 2011.

Volunteer work

- Big Sioux Water Festival (2014-2016)
  - Worked with Dr. Matt Miller at SDSU to provide demonstrations for elementary school children in the area.
- Boy Scouts Chemistry Merit Badge (2015 -2016)
  - Worked with boy scouts to provide assistance in completing various experiments required for their chemistry merit badge.
- Eastern South Dakota Science and Engineering Fair (2016)
  - Judged middle school chemistry projects.

Honors/Awards:

- Graduate Teaching Certificate of Highest Excellence (2015)
- Logue Graduate Student Academic Award (2014)
- Graduate Teaching Certificate of Excellence (2014)
- EMU Chemistry Department Teaching Assistant Award (2013)