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Development and Assessment of Gamified Process-Oriented Guided Inquiry Learning Activities in Undergraduate Large Lecture Chemistry Courses

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DEVELOPMENT AND ASSESSMENT OF GAMIFIED PROCESS-ORIENTED GUIDED INQUIRY LEARNING ACTIVITIES IN UNDERGRADUATE LARGE LECTURE CHEMISTRY COURSES

BY

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

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CONTENTS

ABBREVIATIONS

TEL	Traditional Expository Lecturing
POGIL	Process Oriented Guided Inquiry Learning
GpA	Gamification-POGIL Activities
gpa	Grade Point Average
DFW	D, F, Withdrawal Rates
CLT	Cognitive Load Theory
CLASS	Colorado Learning Attitudes About Science Survey
TOLT	Test of Logical Thinking
DBER	Discipline Based Education Research
ID-DS	Instructor Designed Demographic Survey
ID-PPA	Instructor Designed Pre/Post-Assessment Quiz
ID-MS	Instructor Designed Metacognitive Survey
PISI	Post-Instruction Student Interviews
GQ	Gamification Questionnaire

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ABSTRACT

DEVELOPMENT AND ASSESSMENT OF GAMIFIED PROCESS-ORIENTED GUIDED INQUIRY LEARNING ACTIVITIES (GpA) IN UNDERGRADUATE LARGE LECTURE CHEMISTRY COURSES

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Students who take general chemistry and do not perform well are more likely to pursue an alternative degree or remove themselves from STEM curriculum entirely. Poor academic performance and high student attrition rates in general chemistry courses have resulted in the perception of chemistry courses being gatekeepers for students in pursuit of STEM degrees. Process-Oriented Guided Inquiry Learning (POGIL) has shown promising results in both lecture and laboratory teaching on student performance in chemistry while gamification has been used to enhance student learning experiences to help students grasp chemistry concepts. The current project blends two student-centered approaches, gamification and POGIL, to address student performance in general chemistry. The purpose of this project was to develop gamified-POGIL activities (GpA) as well as assess GpA's effects on students' conceptual understanding of chemistry and development of problem-solving skills. The project involved a quasi-experimental, mixed-methods research approach comparing three teaching methodologies: Traditional-Expository Lecturing, POGIL and GpA. The quantitative assessments included: Instructor Designed Pre/Post-Assessment, NASA TLX, and Test of Logical Thinking. The qualitative assessments included: Instructor Designed Metacognitive Survey, Colorado Learning Attitudes About Science Survey, Post Instruction Student Interviews, and Gamification Questionnaire. Data analysis was done using non-parametric statistics and qualitative coding. The teaching methodologies reported no statistically significant differences between assessment performances, conceptual understanding, and cognitive engagement in metacognitive understanding and cognitive load. However, the POGIL and TEL had significantly more positive shifts on student attitudes towards chemistry concepts and problem-solving skill development compared to the GpA methodology.

CHAPTER 1: Introduction

Motivation of the Study

Studies in discipline-based education research (DBER) continue to advocate for reforms in secondary and postsecondary educational practices. DBER is grounded in the "priorities, worldview, knowledge, and practices" of the discipline being studied[1]. Sometimes asking for reforms comes from a desire to changing the status quo without any defined plan. In order to effectively enact educational reforms there must be a defined problem with a proposed solution. The definition should address an actual concrete problem rather than something vague and hypothetical. Problems must be narrowed and, in some cases, hyper focused. Some may see this as ineffective since problems in modern educational practices are large and systemic. However, dealing with problems in the postsecondary educational system is more akin to the children's game Jenga®. If problems are to be effectively addressed, it must be piece by piece with care and precision. So then comes the question, what is a major problem to be addressed in current postsecondary education? For the most part, a majority of issues can be categorized under one umbrella, student engagement and success.

Student success and engagement are vague terms that seem to mean everything and nothing at the same time. In DBER, however, success and engagement are defined based on performance and are commonly measured using the following areas of focus:

- DFW rates-the rates at which students in a course are academically deficient, receiving a D or an F grade, or are withdrawing, W.
- Attrition rates-the rate at which students are leaving either a course or a major program

- Retention rates-the rate at which students are retained in either a course or a major program
- Student attitudes-the self-assessment of how students feel about an educational environment including, but not limited to, self-efficacy and motivation
- Conceptual retention-the ability to know, recall and apply content knowledge rather than memorize facts

A common misconception amongst educators is the expectation that a large cohort of students are prone to fail a course, regardless of the course's difficulty. However, this is not true. The best refutation to this idea is the performance of students in undergraduate STEM classes, more specifically undergraduate chemistry classes. Undergraduate chemistry courses have a notorious track record of being gatekeeper courses partly because of high DFW rates, high attrition rates, low retention rates, and low self-efficacy which can be tied to student attitudes[2-4]. When these negative performances are left unaddressed, students do not naturally improve over time[4]. What previous DBER researchers have found is that the teaching methodology used to instruct students can explain part of the currently somewhat poor state of student performance. The most common teaching methodology used in this context is traditional expository lecturing. Lecturing as a teaching methodology usually involves low-levels of student engagement and high-degrees of reciting factual knowledge. Because of the limitations of lecturing, students are often reported to be apathetic, limited in their problem-solving skills, and have high-DFW rates and low-retention rates (in both course retention and conceptual retention)[3, 5-8]. When offered an alternative teaching methodology, students of similar demographics performed better than their counterparts in the same course that used lecture-based teaching only. The reason why is not entirely clear for a majority of alternative teaching methods, however what has been made clear, especially in active learning based alternative teaching methods, is that student engagement helps to improve problem-solving skills which has led to improvements in student's academic performance and conceptual retention[9-14].

A significant hinderance to student learning is the experience of cognitive overload. Cognitive overload is where students can no longer effectively process information and risk forming significant misconceptions from their improperly processed information. In a book chapter on information overload, Ram Lamba states: "A cook follows a recipe without having any knowledge of why certain spices have to be added in a specific order to get a specific taste, whereas the chef knows exactly why the order is important and, in case a specific spice is missing, can make a substitution to achieve the required taste. As science educators, it is more important to prepare 'chefs' rather than 'cooks'"[3]. Instructors must seek to develop students who are chefs and not students who are just cooks. Cooks have a significant passive engagement in the classroom and are expected to accept but not necessarily understand information in the learning environment[3]. Lecture versus active/alternative forms of learning is a very simplistic view of the issue. The goal is to develop and define specific modes and methods different from traditional lecturing that can improve student engagement. This study seeks out to both give clarity to the mechanics that benefit students in certain teaching methodologies as well as the limitations of implementing said alternative methodologies.

Importance of the Study

There are many reasons to believe that the traditional lecture format is limited in its effectiveness as a pedagogy. One endemic reason can be uncovered by simply considering the roles of the participants in this educational experience[5]. Students often are passive observers in the lecture while instructors disseminate information that they perceive to be important. For an alternative teaching methodology to be successful students must be active participants in the learning process. Process Oriented Guided Inquiry Learning (POGIL) is an active learning methodology that not only provides students with an active role but also allows them to improve their problem-solving skills by incorporating specific roles into the learning environment. Another teaching methodology that has shown immense promise is gamification, a methodology that encourages active student engagement as well as has a record of improving student motivation.

The answer seems clear, to improve student success and engagement instructors must incorporate alternative active-learning teaching methodologies, but it is not that simple. For one thing there are several limitations to the studies conducted such as low statistical power, sample size, and a restricted research time frame[15-18]. Another limitation to consider is the interest of instructors and students in adopting alternative teaching methodologies. Various studies have found that despite the academic success of alternative teaching methodologies compared to lecturing, low student and instructor buy-in can still be persistent[19]. Buy-in relates to the likelihood that an instructor or student will be amenable to the adoption of a new assessment tool or teaching methodology.

Purpose

While POGIL has shown to improve student performance, gamification has shown to improve student engagement and motivation. By combining the two, it is proposed the newly formed teaching methodology can increase student success and buy-in when compared to traditional expository instruction. The purpose of this study was to develop a gamified POGIL teaching methodology and assess its effect on student attitudes and performance. Three main literature gaps are addressed in this study: lack of empirical studies in gamification literature, assessment of cognitive load on student attitudes in learning environments, and mechanistic study on how POGIL and modified POGIL instruction affect student performance. The GpA research study describes the development of gamified POGIL activities and how it is implemented in an educational setting. The GpA was used in a large sized general chemistry course, courses with 100 or more students, and assessed against two other teaching methodologies, an unchanged POGIL and TEL. Two research questions were used to assess this study:

1. What is the impact of GpA on student academic performance, conceptual understanding, and engagement?
2. How does GpA affect small group interaction & problem-solving skills?

Each teaching methodology was implemented in the course as an intervention course taught in tandem with the main course. Collected data was analyzed using both qualitative and quantitative metrics. Chapter 2 details the literature review that influenced the study, while Chapters 3 and 4 details the experimental methodology and analysis tools used.

CHAPTER 2: Literature Review

Current State of Education

Current metrics in educational literature report high attrition rates, high DFW rates, and low retention rates in STEM courses in both local midwestern and national university contexts[2-4]. A specific STEM curriculum that has suffered from the negative educational course design and performance has been first- and second-year chemistry courses. Difficult content and low student performance have resulted in general chemistry being perceived as a gatekeeper course that is forcing student to seek alternate degree paths compared to their original STEM degree program[2, 3, 5]. To maximize student success and improve student performances a review of present teaching methodology is recommend.

Traditional Educational Methodology

Lecture-based instruction is the most common educational methodological approach used in post-secondary undergraduate instutions[19, 20]. The act of lecturing itself can be incorporated into various methodological approaches since it is based on the primary instructor disseminating knowledge to the students. However, as observed in educational based literature, most reported instances of lecturing can be described as traditional expository learning (TEL). TEL can be described as an instructor centered methodology where instructional time is spent predominately using lecture to disseminate information to students who, in return, are tested on their ability to repeat and recall that information. Because of the commonality of TEL and its prevalence in undergraduate education, it has been difficult to differentiate between the effectiveness and ineffectiveness of the methodology. The exclusivity of the use of lecture-based and expository teaching methods has been called into question[6, 8]. A majority of publications in Discipline Based Education Research (DBER) indicate students prefer alternative teaching methods over TEL when performances improved on measured metrics (instructor written-exam, standardized exams, course grades)[10-13, 19]. A minority of studies indicate students prefer TEL to alternative teaching methods, however, this is not because students perform better in lecture-based settings compared to alternative methods. Instead, it is most likely because students are most familiar with their expectations and responsibilities in instructor centered lecture-based teaching methods compared to alternative teaching methods[19]. Students participating in a TEL methodology are expected to respond passively in a lecture setting and listen to the information presented by the instructor. Though they have the freedom to ask questions and engage in lecture, students commonly are more likely to respond passively to the instruction. Because of the passive engagement and dependence on the instructor, TEL restricts students' ability to grow in problem-solving skills, transfer learning content to new situations, and grow in educational autonomy[5, 7]. Regardless, if it is the responsibility of the instructor or the student to be engaged in the lecture, TEL alone does not offer a methodological approach to engage students in the learning process.

Process-Oriented Guided Inquiry Learning

Various alternative teaching methods have been tested against TEL, the most common being guided inquiry-based learning methods[10, 12]. The guided inquiry methodology is an umbrella of teaching methodologies that are student-centered and focused on building a students' educational autonomy and problem-solving skills. Though various guided inquiry methodologies populate DBER literature, Process

Oriented Guided Inquiry Learning (POGIL) has shown much promise in more recent publications[10, 14, 17, 20-23]. POGIL is a student-centered guided inquiry teaching method that incorporates learning activities, scaffolded instruction, and specific assigned student roles. To understand POGIL there are four aspects of the teaching methodology that must be understood: instructional framework, the methodological approach of POGIL activities, student responsibilities, and instructor responsibilities. POGIL incorporates the instructional frameworks of constructivism and the learning cycle.

Constructivism is a fundamental framework in a majority of guided inquiry teaching methodologies[24, 25]. The learning cycle is a framework specific to POGIL and includes a three-phase learning process that takes place during each instructional period. Those three phases are exploration, concept invention, and application[10, 21, 23]. The exploration phase is the initial phase of learning in which students interact with content by collecting data or observing what is presented to them, develop hypotheses to explain the content and test these hypotheses against different questions[10, 12, 26]. Students in this phase traditionally develop a model and use that model to explain and describe patterns in the content. For example, students may be given a set of data that lists student final exam grades versus their overall gpa. In the exploration phase students can develop an equation that helps describe how well student gpas may predict final exam grades. Students will then take this information and transition into concept invention. Concept invention is where students use the model they developed in the exploration phase to answer questions and create new terms that describe the model[12, 26]. Open-ended questions connected to the given activity or developed by the students are used to test the model and solidify their understanding of the content. Once there is general agreement upon the information understood in the concept invention phase students then transition into the application phase. Application is where the students take the models and terms they have developed and apply them to new situations[10, 26]. This is the phase in which students grow in deductive reasoning and problem-solving skills. From growth in problem-solving skills students are able to have a stronger understanding of the content and decrease their misconceptions of the content[23].

When incorporating the POGIL teaching method into a classroom context a specific type of activity must be used. POGIL activities are validated through a network of research studies and certified implementors. Each POGIL activity is composed of three specific components: schematics, example questions, and critical thinking questions[26]. The schematics are graphs, tables, and figures that relate to the content being taught during the instructional period. The main purpose the schematic serves is to introduce a minimal amount of content to the students. Rather than having all of the information introduced in one lecture, students are given incremental pieces of information[27]. This allows for students to reduce the amount of cognitive load that they are experiencing during the instructional period. Example questions and critical thinking questions are used for different purposes, but both are scaffolded such that they increase sequentially in difficulty. Example questions are used to help guide students during the beginning of the concept intervention phase and are not required to be graded. Critical thinking questions are used during the application phase to help solidify the students' understanding of the content and must be graded[13, 23].

Student and instructor responsibilities are a vital part of POGIL instruction and significantly differentiate it from other teaching methodologies. POGIL requires working in groups of three to five students. Students are assigned one of four roles to fulfill during the POGIL activity: Manager, Reflector, Technician and Presenter[10, 12, 26]. The Technician performs all technical operations of the group, making calculations and using a computer if need be. The Reflector observes and comments on group dynamics and behavior with respect to the learning process. The Presenter presents oral reports to the class. The Manager manages the group, ensures everyone is fulfilling their roles, and makes sure everyone participates. Student roles and groups can be self-selected or assigned by the instructor of the course. The roles or groups themselves do not have to be the same between each instructional period. A benefit of the role-based system in POGIL is the flexibility. Though students have specific roles they are not restrained to what they can and cannot do in the activity. Instead, their roles help to specify what their primary responsibilities are in the activity. For example, the Technician is equally responsible for answering the example and critical thinking questions as the other members of the group. However, if the group needs research to be done on a specific aspect of the activity it would be the primary responsibility of the Technician. With the exception of the Manager, all of the student roles can be co-assigned to another student if the group is larger than four or double assigned if the group is less than four[12]. The instructor's main responsibility during the POGIL instructional period is to act as the facilitator. This means asking probing questions during the POGIL activity to help lead students to clearer understanding and address misconceptions[21, 26]. Instructors using POGIL actively engage students in the learning process encouraging the development of their problem-solving skills. This is in stark contrast to instructors participating in lecture-based instruction who mainly communicate information and do not actively engage students in the learning process. Since students are not actively engaged and instead are bombarded with information there is a higher risk of students experiencing cognitive overload[19, 26, 27].

Reported in literature POGIL has various positive impacts on student growth and development such as a decrease in DFW rates and improved overall course grades[10-13]. Two specific positive impacts pertinent to this research project are the impact of POGIL on assessment scores and problem-solving skills. Assessment tools can either be self-authored assessments made by the instructor or exams scores from standardized validated assessments. When comparing performances of a control group, commonly a group taught using a lecture-based teaching method, to a group taught using POGIL it was revealed that the students participating in the POGIL group performed better, evidenced by higher assessment scores, compared to their traditional lecture-based counter-part[10, 13, 14, 28]. Part of this can be explained by POGIL's positive impact on student's problem-solving skills. In the TEL methodology students are expected to repeat and recycle what is explained during the lecture period. Students accept information from the instructor but do not necessarily understand the information[3]. However, POGIL allows students to work in groups which alleviates the amount of cognitive load experienced by each student individually. Instead, students share their cognitive load allowing for more room in their working memory to process and store the information taught during the instructional period.

Though POGIL has shown much promise in helping students succeed in comparison to lecturing alone, there are present limitations that have yet to be addressed. One of those major limitations is the amount of student buy-in. Buy-in is the likelihood of students to participate and accept an alternative teaching methodology. Low buy-in means students are less likely to participate while a high amount of buy-in means students are more likely to participate. Though POGIL has shown success in improving student performance, there has been a struggle with encouraging initial student buy-in[22, 23]. There are various reported explanations to this phenomenon best explained by Rodriguez and group. The two most prevalent to this study are views of group work and the role of the instructors. Students have reported a negative view of group work when the participants in the group do not properly maintain an active role or help the group. Though students do not have to know all of the information, if they are not engaged in the learning process it is perceived that they are dependent upon other group member doing a majority of the work. Students also do not have a favorable view of the role of the instructor during POGIL instruction. If the instructor is not actively engaged in the learning process and is overly hands-off then students perceive the instructor has too minimal of a role. This potentially discourages student autonomy by under preparing the students and not properly teaching them.

Gamification Based Methodological Practice

As stated before, alternative teaching methodologies have recorded benefits in literature compared to traditional teaching methods. One of the limitations of most alternative methods, specifically guided inquiry methods, is with student buy-in[19]. To improve student buy-in a teaching methodology should incorporate mechanisms to help improve student motivation and student engagement, two major factors in improving student buy-in. Gamification has shown major promise in current research literature with providing the appropriate mechanisms to improve student motivation and engagement[18, 29-32]. Gamification is the application of game elements in a non-game context. The elements could be, though not limited to, points, badges, leader boards, levels[7, 15, 16, 18, 31-43]. An important clarification is the difference between Gamification and other Gaming-Inclusion methodologies as seen in Figure 1. There are three different Gaming-Inclusion teaching methodologies most prevalent in literature: Gamification, Serious Gaming, and

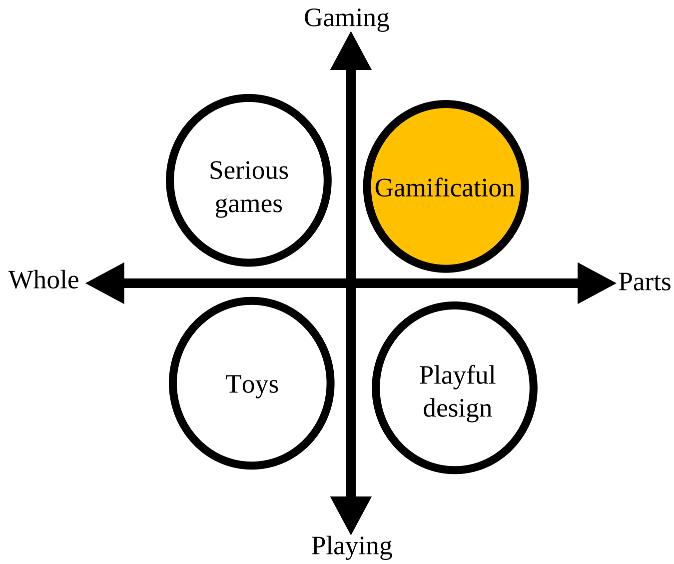

Figure 1. Mechanisms and elements used to differentiate between Gaming-Inclusions methodologies

Game-Based Learning. Serious Gaming involves using developed games for non-entertainment purposes, the entire lesson is centered around a game, while Game-Based Learning uses partially gamified elements in an educational setting for real-life training and application[30, 33, 43, 44]. In Gamification, game elements are used to help engage students in the learning process, reinforce knowledge, and develop skills such as problem-solving, collaboration and communication[39, 44]. Assignments used in Gamification are often developed by the instructor and center around three principles: mechanics, dynamics, and emotions. Mechanics are the goals, rules and rewards of the activity, dynamics are how the students interact with the mechanics, and emotions are how players feel toward the gamified experience[40]. There is no specific design pattern to how Gamification activities are developed, however there are various elements that have been found to be consistent through different studies. By using gaming elements, Gamification activities engage students in the learning process by allowing them the freedom to succeed and fail. The teaching methodology also provides the opportunity for rapid feedback on whether their understanding of the content is correct or incorrect providing an opportunity to address misconceptions[30, 35, 36, 38, 44]. Gamification has been produced and used in various educational and non-educational context, such as business and marketing, however the context of most importance to this study is the use of Gamification in STEM education as seen in Table 1.

Table 1. Summary of Gamification Studies in Chemistry Education

Game Title	Chemistry level	Game Dynamics	Student size	General Results
"Where's Ester?"	Organic Chemistry	"Guess Who?"	Not reported	Researchers self-reported positive results but with no evidence
M. Antunes Game	General Chemistry	Board game, roll dice, answering questions	48	Researchers self-reported positive results but with no evidence. Students in experimental performed better than the control on a researcher made post assessment.
Go Fischer	Introductory Organic Chem	"Go Fish", card matching game	69	Majority of students in a reported Likert survey enjoyed the game and didn't find it difficult to play
Elemental Periodica	High School	Bingo style	250	Researchers self-reported positive results but with no evidence
Groupica	High School	Matching card game	250	Researchers self-reported positive results but with no evidence
Compoundica	High School	Board game	250	Researchers self-reported positive results but with no evidence
GAPc	Introductory Chem	Gamification (points, badges, leader boards)	61	Mixed results from self-reported impersonal interviews, no strong evidence
CHEMCompete	Organic Chemistry	Matching card game	46	Student activity quiz scores increased while their survey results showed mixed results (though generally positive)
CHEMCompete II	Organic Chemistry	Matching card game	42	Similar results to CHEM Compete I
Stereochemistry Game	Organic Chemistry	Board Game	142	Student survey results Playability- majority of students found the game easy to play and fun Content- Mixed result of students don't feel the questions adequately cover content seen in classroom

				Usefulness-Majority of students found the game useful in the realm of cooperation and game innovation
ChemKarta	Organic Chemistry	Card game	15	None reported
Chemical Alias	General Chemistry	Board game	>10	Negligible self-reported positive results
Orbital Battleship	General Chemistry	Board game	50	Negligible self-reported positive results
Organic Mastery	Organic Chemistry	Board game	Not reported	None reported
Chemical Nomenclature	Introductory Organic Chem	Mobile game	329	Survey results generally positive, statistical difference in scores between experimental and control groups
MOL	Organic Chem	Board game	103	Fairly positive results in survey interviews
Mobile Gamification	Primary School (non Chem)	Mobile game	102	Fairly positive results in survey interviews

Yildirim and group report a succinct description of how to develop a gamified educational activity[45]:

- Knows that the lesson is actually a game and succeeds in finishing the game by completing the tasks
- Is aware of the advancement structure and fulfills the requirements
- Cooperates with friends inside and outside of the class
- Is more successful in a favorable competitive environment
- Knows what is required to earn points and earns points by putting his/her knowledge into practice
- Knows what is required to earn experience points (xp) and earns experience points by putting his/her knowledge into practice
- Knows what is required to level up and levels up by putting his/ her knowledge into practice

- Knows what is required to earn badges and earns badges by putting his/her knowledge into practice
- Knows what is a leaderboard and makes efforts to advance in the league

Rabah and group also describe development of a gamified activity[39]:

- Visible status-informs students about a task's completion status or else shows students how they're progressing
- Social engagement-competition, cooperation, and collaboration
- Freedom of choice-implies that students are free to choose whichever task(s) they want to complete
- Freedom to fail- students were given the chance to submit assignments again to revise their work without a penalty.

M.E. Gredler proposed a framework of game development[46, 47]:

- Winning the game should be more than a matter of luck.
- The student should win the game as a reward for his or her knowledge of the subject matter
- The game must provide information relevant to the content; that is, it must show the student which aspects are most important for gaining knowledge, and it must address the subject under study
- Dynamics of the game must be easy to understand, and the participants must find it interesting
- Students must not lose points for giving incorrect answers; rather, they should be encouraged to reconstruct knowledge

- The teacher must be aware that students who demonstrate good knowledge of the subject will not always win the game; thus, the game must be a beneficial exercise in which all students gain some knowledge and content related skills.

Overall gamification has had mixed results, mostly positive, in the reported literature[7, 16, 30, 42, 48]. As recorded in literature Gamification activities have been shown to improve student engagement and motivation both intrinsically, learners being interested in the learning process, and extrinsically, learners engaged in learning[35]. Intrinsic motivation is improved when student autonomy, competence, and readiness are addressed. Gamification, through the various implemented elements, addresses each of these needs by providing a system of rules and task that leads to the mastery of content. Though there is a greater need for comparison groups in gamified studies[38], there have been studies comparing gamified groups to non-gamified groups. Khe Foon Hew and group reported a similar result in which students in a gamified group did not perform better than the control but had a more positive result in motivation as a result of the game elements to attempt difficult tasks[49]. However, some studies have reported different results. For example, Ibrahim Yildirim and group reported a semester long study comparing a gamified-flipped classroom method to a non-gamified-flipped classroom method in a teaching principles and methods course a part of a southern state university in Turkey. Using a pre- and post-test the author reported there was a significant difference between the gamified and non-gamified group in which the gamified group performed better than the non-gamified group[45]. Similarly, Joana Dias and group reported a four-semester long study comparing a gamified group to a non-gamified group in an operations research management science course. Overall, it was reported the gamified group performed quantitatively better than the non-gamified group with more engagement and motivation[29]. Gamification showed to benefit students and have positive effect on their short term knowledge retention[7].

Though largely successful in literature, Gamification has several limitations. Despite the reported success on students skills, Gamification has had limited to no reported improvement on student academic performance[50]. Some studies have indicated that the results of gamification are because of the novelty of the methodology and would not be consistent in a longitudinal study[51]. Some studies have reported a negative academic outcome over a long period of time. Partrick Buckley and group make a recommendation of pairing gamification with other teaching methods as a preventative measure against demotivation. The author quotes "[demotivation] does not necessarily dent [gamifications] utility, rather, it calls for the inclusion of gamified learning interventions as part of a range of learning interventions, chosen in a manner that ensures no type of learner is systematically disadvantaged"[35].

Cognitive Load Theory

Both guided-inquiry teaching methods and gamification incorporate cognitive load theory[18, 27, 33]. Cognitive Load Theory (CLT) is an informational processing theory that describes human cognitive architecture and how an individual's memory works. The theoretical framework has been used in various social science research context[52-55], however it has been highly influential in educational research context to explain how students learn and store memories as shown in Figure 2[56, 57].

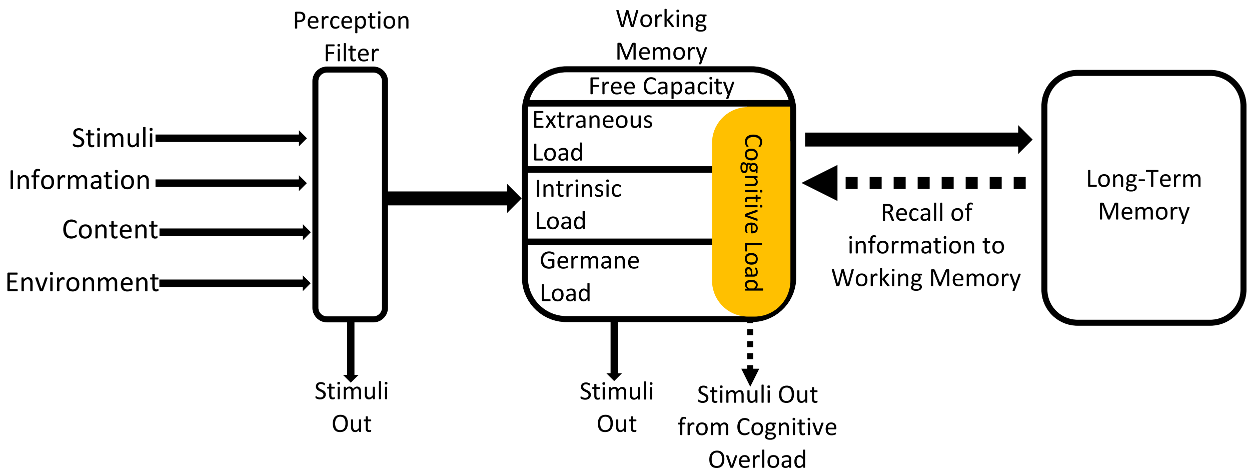

Figure 2. Adapted information processing model developed by Cranford et al.

Individuals interact with stimuli (information, content or environment) where it is processed through a perception filter. A perception filter takes that stimulus and helps an individual to either filter out the stimuli, not store it, or to process the stimuli in the working memory. Stimuli processed in the working memory can be stored semi-permanently but eventually must be processed out or stored permanently in long-term memory[52, 56-59]. The working memory is broken in to two portions, Free Capacity and Cognitive Load. From the working memory information, or knowledge, is stored and organized in the long-term memory. According to Cognitive Load Theory the there is a limited capacity in the working memory but a virtually unlimited capacity in long-term memory[57, 60]. Information can be recalled from the long-term memory into the working memory to help process incoming stimuli.

Cognitive overload describes the phenomenon in CLT in which the individual has limited Free Capacity and an overwhelmed Cognitive Load. This could lead to improperly processed stimuli, which in education can result in the development of misconceptions, or unprocessed stimuli, meaning content is not stored in the Long-Term Memory but instead is filtered out[52, 59, 60]. Free Capacity is the amount of working memory available to process information, so the less Free Capacity available the more likely the individual will experience cognitive overload. To understand how Cognitive Load can be overwhelmed there must be an understanding of the three types of loads, extraneous load, intrinsic load, and germane load. Extraneous load is when the individual engages in cognitive processing that does not support the overall learning process[56]. This could be a result of poor activity design that requires the individual to process more information, impeding student growth. The lesson designer can reduce cognitive load expressed by extraneous load by focusing on four principles: multimedia, using text and pictures rather than only pictures; modality, present a text auditorily when possible if combined with picture; coherence, exclude no essential information in multimedia learning environments; and split attention, integrate information together rather than separately when possible[60]. Intrinsic load takes place when an individual engages in cognitive processing that supports the overall learning process[56]. As the number of elements in the learning process increases, the possible intrinsic load experienced by the individual also increases. Intrinsic load in part can be reduced by the individual by using their prior knowledge to chunk, or segment, the information. However, the instructor can lessen the intrinsic load by reducing element interactivity through step-by-step information presentation, and pretraining, providing the learner with information about the content before starting with the learning material[60]. Germane load takes place when an individual engages in deep cognitive processing[56]. Though high intrinsic and extraneous load are generally negative, high germane load does not necessarily have an adverse effect on individual’s ability to process information because high germane load reflects an individual is engaged in the learning process.

In an educational setting, cognitive overload is most often expressed when attempting to process too much new stimuli at once. Dr. George Miller proposed that an individual in their working memory can process seven plus or minus two pieces of information simultaneously[56, 58]. When an individual is expected to process more than this, it can interfere with their ability to effectively process and comprehend the content presented to them. A good example of this is by Lamba and group in their paper on memory[3]. The task they present is to rearrange words into numerical values and then arrange those values in the correct numerical order as seen in Table 2.

Table 2. Lamba Cognitive Load Theory Task

Fifteenth of February
November fifteenth
Fifteenth of February forty five
November fifteenth nineteen forty nine
December twenty nine nineteen forty one

For example, Fifteenth of February is 152 which is rearranged to 125. The task gets harder and harder the more material that an individual has to process and keep track of. After the third line most individuals experience some form of cognitive overload and begin to work slower, make mistakes, or stop the task all together. In order to alleviate cognitive overload, there are generally two recommendations, increase the knowledge of the individual and chunk the material, or address the cognitive load types in the working memory. Both recommendations can fall under the responsibility of the instructor or the learner. As the knowledge of the individual increases, the ability to process new related information also improves which results in a reduction of cognitive load[52, 61]. Chunking is a term that describes when information is paired together to reduce the number of stimuli that needs to be processed. For example, when looking at the formula NaOH a novice learner will see individual letters and not know how to process the information, however an expert will see the separate Na and OH and be able to interpret the compound and other information paired with it[3]. Besides knowledge being used to chunk information for the learner, the lesson developer (or the instructor) can also chunk information to help reduce cognitive load. Developers are encouraged to create lessons that engage leaners in the learning process in order to decrease cognitive load and improve the Free Capacity to process new information.

To measure cognitive load the Paas[52-54, 56], NASA-TLX[53, 55, 56, 62, 63], Stroop task[56], Heart rate[56], blink rate or eye tracking data[56] can be used. Each can be categorized as either performance techniques, subjective techniques, or physiological techniques. NASA TLX is an assessment tool developed by the NASA Ames Research Center that measures the workload of a specific task self-reported by a participant in that task. There are six factors that affect the measured workload of a participant: mental demand, physical demand, temporal demand, performance, effort, and frustration level. Mental demand is how much mental and perceptual activity was required (e.g. thinking, deciding, calculating), physical demand is how much physical activity was required (e.g. pushing, pulling, controlling), temporal demand is how much time pressure is felt due to the rate or pace of the task, performance is how successful the participant thinks they were in accomplishing the goals of the task set by the experimenter, effort is how hard did the participant have to work to accomplish said level of performance, and frustration level is how insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent the participant feels[62]. Each of the factors are compared as a pair-wise comparison. The results from these comparisons is tallied from 0, not relevant, to 5, more important than any other factor, and determines the weight of each factor in later analysis. Each individual factor is then scored on a scale from 0 to 100 in increments of 5. The overall workload score for each participant is computed by multiplying each rating by the weight given to that factor from the pair-wise comparison. The sum of the weighted ratings for each task is divided by 15 (the sum of the weights)[62]. One of the critiques found in literature in using CLT is the lack of specificity in determining what parts of the task result in what type of load and what load type ultimately results in the cognitive overload[57, 60]. Cognitive Load Theory has been used to measure the workload of participants in various fields such as psychology[54, 55], medical practice[52, 53], and education[56, 58]. In a study conducted by Aldekhyl and group, cognitive load was used in order to measure participants' potential to learn complex skills and gain expertise. It was proposed the lower the cognitive load the higher the potential expertise of the participants in the simulation-based clinical practice. Aldekhyl ultimately proposed cognitive load could be used to determine how to design instruction in a way that the working memory produces increasingly expert-like schema construction[52]. In other words, CLT possibly could be used to measure the potential of instructional techniques to maximize student success and optimize those instructional techniques. Though the report was referencing short training interventions in the medical field, it shows promise for the purposes in short-term instructional intervention, both in CLT and NASA-TLX.

Social Constructivism

Similar to Cognitive Load Theory, Constructivism is a popular theoretical framework used in guided-inquiry and gamification teaching methodology studies[24, 25, 30, 64]. Constructivism states that knowledge, in an educational setting, is formed from pre-existing knowledge and is constructed by the student rather than formed and transferred from the environment. Jean Piaget laid the foundational framework for constructivism through his theory of intellectual development. The traditional view of knowledge states that knowledge matches reality, however Piaget states that knowledge falls into three categories physical, logic-mathematical, and social[1, 65]. When forming knowledge students take preexisting cognitive structures and use them to interpret data into new schema. There are a variety of types of constructivism, such as radical, personal, critical, and contextual constructivism, with social constructivism being the most pertinent to this study. Social constructivism states that the construction of knowledge is supported by the social interactions with others in the learning environment[12]. Though there are different types of constructivism, all forms of constructivism function under similar assumptions: Individuals and communities build up knowledge; Social interactions, whether they are individual, social, or cultural, play an important role in the construction of knowledge; The learning construction and the language surrounding the knowledge being constructed must be useful, practical, and "adaptive"; and Learning and language serve to bring coherency to the individuals experiences and the knowledge base of the community[66]. Learners construct further knowledge by modifying that which they already have, they are not blank slates[1, 64]. When individuals construct knowledge themselves from previous knowledge, they are more like to retain the content.

Literature Gap

Despite the success seen in current literature there are significant gaps in recent published methodology and in implemented alternative teaching methods. Current chemistry education research methodology requires more quantitative studies to be presented to validate reported data. Research currently presenting quantitative studies have been underpowered meaning that though short-term, small-sized studies report statistically significant data, the data is not reproducible in larger cohorts[1]. To improve the statistical power of research studies, larger sample sizes must be recorded and reported. Sample sizes coincidentally are also an issue amongst POGIL and gamification publications[12, 15-17]. A greater clarity in how alternative teaching methods, specifically POGIL, affect student attitudes is an important aspect to observe. This potentially provides clarity on why students perform better in POGIL settings but are resistant to the methodological change[23]. Gamification studies suffer from methodological short comings. Most studies lack quantitative metrics, have significantly low sample sizes, and are limited by short term interventions[15, 16, 18, 37, 39]. It has been recommended that future research in gamification seek to address the potential negative, adverse, or non-preferable effects of gamification as well as implementing longitudinal studies[15].

CHAPTER 3: Methodology

GpA Development

To properly implement the Gamified POGIL teaching method, a GpA activity had to be developed. The development of the GpA was conducted in three phases: a review of essential chemistry content, POGIL techniques, and an initial literature review of current gamification techniques. A clear understanding of how current undergraduate chemistry is taught helps to develop the GpA in such a way that it addresses current shortcomings of traditional teaching methodologies. A paper by Alex Johnstone described the concept of macro- and microchemistry, two scopes in which chemistry content is taught[1]. Macrochemistry is easier for students to grasp because the content is large scale in observation such as ice melting or physical changes. Microchemistry requires students to grasp small scale phenomenon such as chemical symbolism or intermolecular bonding.

As students are introduced to chemical concepts, they must process both the macro- and microchemistry. With most students being novices in chemistry, cognitive overload can take place when required to process a large amount of microchemistry, a requirement of most undergraduate chemistry courses. Part of the reason for this, as pointed out by Johnstone, are the unreasonable cognitive demand imposed by chemistry instruction that focuses on different levels simultaneously[1]. To address this, the GpA methodology incorporates model development as a part of the instructional period, an element of gamification and POGIL. As stated by Bodner, working models of reality are responsible for students' developing misconceptions which are concepts or ideas which from the point of view of the average professional lead to unacceptable solutions or answers to questions or problems in the context of a course[1, 65]. To determine the chemistry content that would be used for the GpA, five curriculum resources were crossed-referenced. Each curriculum resource detailed major chemistry topics that the authors recommend be taught in undergraduate chemistry courses, general chemistry, organic chemistry, and inorganic chemistry[67-69], as seen in Table 3.

Table 3. Important content recommend being covered in undergraduate chemistry courses

Gillespie	Atkins	AP Chemistry Big Ideas	ACS General Chemistry Curriculum Map Anchoring Concepts	CLUE Core Ideas
(1) atoms, molecules, and ions (2) the chemical bond (3) molecular shape and geometry (4) kinetic theory chemical reaction	(1) matter is composed of atoms (2) elements form families (3) bonds form by sharing electron pairs (4) shape is of the utmost importance (5) molecules interact with one another	(1) atoms (2) chemical and physical properties (3) reactions: rearrangement of atoms and electrons (4) rates/kinetics (5) thermodynamics/energy (6) bonds and interactions	(1) atoms (2) bonding (3) structure/function (4) intermolecular forces (5) chemical reactions (6) energy and thermodynamics (7) kinetics (8) equilibrium (9) measurement and data	(1) atomic/molecular structure and properties (2) electrostatic and bonding interactions (3) energy (4) change and stability in chemical systems

(5) energy and entropy	(6) energy is conserved (7) energy and matter tend to disperse (8) there are barriers to reaction (9) there are only four fundamental types of reaction	(10) visualization and scale

From these resources nine topics were chosen to be converted into GpAs: atomic structure, isotopes, ions, chemical reactions, ionic bonding, covalent bonding, intermolecular forces, periodic trends, and acid-base chemistry. At this stage it is understood that GpA must incorporate model development and the chemistry content. POGIL has previously constructed lessons that allow opportunity for model development and active engagement in the learning process. Recall the major elements of POGIL discussed in CHAPTER 2: LITERATURE REVIEW. The instructor functions as the facilitator while the students are assigned a role of either Manager, Recorder, Technician, and Presenter[10, 12, 26]. A single trained instructor in POGIL can manage 15 groups, or 60 students, maximum[14]. Because of this the GpA must incorporate student roles, but also be simple enough to train teaching assistants to implement if the class size exceeds 60 students. Each POGIL lesson takes about 40 minutes in which students are required to complete critical thinking questions. Though it is not required, it is heavily encouraged that students also complete the exercise questions as part of the scaffolded instruction[10, 13, 23]. A traditional POGIL teaching section can be broken into three parts: the POGIL activity, the role of the students, and the role of the instructor. A traditional POGIL activity will have three sections based on the POGIL guidelines which include schematic, exercise, and critical thinking[26, 38]. The schematic provides a brief figure that introduces the most basic content of the chemistry topic. The exercise section involves introductory questions that students with basic general chemistry knowledge should be able to answer. This section provides the students with a clarity of how they should be answering the questions in the critical thinking section. It also provides an introduction to the content and an opportunity for students to begin scaffolding their knowledge in order to build on their developing schemas[70]. The critical thinking section involves questions which get progressively harder. It has been recommended in past literature to ease students into POGIL instruction[23]. Because of this, students participating in the this research study were only required to complete two sessions of the teaching intervention.

When developing activities to be implemented in a gamified methodology it is essential to know what gamified elements will be used. Recall the major elements of successful game activity development discussed in CHAPTER 2: LITERATURE REVIEW. In summary, to create a successful game activity the developer must encourage collaboration and social engagement, have clearly defined rules, and have clearly established goals and rewards. Since the gamified elements will be combined with the POGIL elements, it is beneficial to use game elements that have been established in chemistry education literature already as seen in Table 1 in CHAPTER 2: LITERATURE REVIEW. On large scale, gamified studies in chemistry education incorporate either card-games or board games[71, 72]. A successful use of card-games as a gamification method usually incorporates different categories and matching strategies[47, 73-75]. Antunes and group developed a similar methodology to what was used in this study in which they compare a non-gamified group to a gamified group. Their game used topics similar to this in this study such as intermolecular forces, polarity, and molecular geometry[46].

Students in group 1 had a dialogue-type lecture, then played the game while group 2 had a similar dialogue-type lecture but did not play the game[46]. Battersby and group developed a go-fish style card game teaching organic nomenclature, functional groups, and structures. In a Likert scale survey a majority of students reported that they liked the game and didn't find it difficult to play[75]. An important measure that has reported positive views to keep in mind are students' attitudes toward the gamified experience. Attitudes can be summarized into three categories: Playability, Content, and Usefulness[76]. Playability states that an activity or game should be easy to play, be age or skill appropriate, promote greater interaction among students, and not penalize students for wrong answers. Content refers to an adequate representation in the activity of chemistry content as seen in the classroom. Usefulness refers to an activities ability to help participants understand the intended content and build a cooperative environment.

Description and Implementation of GpA Methodology

1. GpA

The GpA was developed to be a matching card game activity. The activity was separated into five categories (matching, example, reactions, application, and critical thinking) with each category getting progressively harder. The matching category matches terms and general definitions covered in the topic that basic general chemistry student would be expected to know. The example category uses symbols and imagery that introduces the most basic problems solving question in the topic. The reaction category uses examples of reagents and products and how chemical reactions relate to the chemistry topic. This category also serves as the transition from basic general chemistry content student to more advanced content that may require some prior knowledge. The application category uses a direct relationship of real-life examples or real-life cause and effect relationships that relate to the topic. The critical thinking category is the most difficult category and it requires students to complete a pattern or trend. The POGIL lesson that goes along with GpA has four sections: the schematic, the activity, the exercise, and critical thinking section. The schematic, exercise and critical thinking questions are similar to their purpose in a traditional POGIL setting. The activity section involves two questions where students can record common trends that are evident in the matches they observe in the card game. Each question in the critical thinking section corresponds in some way to the categories in the GpA game, i.e. the harder questions correspond with the harder game categories. Along with the developed POGIL activity, the traditional POGIL roles have been modified for the sake of GpA. The Technician in gameplay will help distribute cards to players, shuffle the card decks if needed, and record the player's scores in the game. The Reflector will be responsible for recording matching patterns, incorrect matches amongst their group, and clarifying answers or disputes amongst players. The Presenter is responsible for recording questions and communicating with the instructor. The Manager will help everyone to participate and lead discussion during the POGIL lesson. If there are more than 4 students, then the Technician or Reflector roles can be assigned to more than one student. If there are less than 4 students, then one student will retain both the Technician and Reflector role. Students participate for 55 minutes alternating between 5 minutes of active gameplay and then 5 minutes of discussion. During the discussion students answer two of the critical thinking questions in the POGIL lesson.

2. GpA Rules

The Technician separates the cards into the five individual categories (each category has a unique color) and distributes one card per category to each player. All remaining cards are placed face down in a deck in the center of the game board in the solid color corresponding to the category. One card is placed face up in the white space outlined by the color corresponding to the category. Players must match the face up card on the game board with a card in their hand. Once a match is made the player puts both cards face up in front of them. The player then takes the sum of the top right number of the matching cards, this sum is the amount of points the player scores based on the match. The player then pulls the top card from the category they matched with and place it face up on the game board and then pull the top card from any category for themselves. If there is no match possible between the player and any face up card, then the player must draw a card from a category or trade cards with another player. If a player has a match of cards in their hand, then they can place the match in front of them and pull the top card from any category for themselves; this can happen at any time and does not have to happen on a players turn. The Reflector will record all the correct and incorrect matches throughout the round. The Technician records all the scores that players have during and at the end of each round. Each round ends after 5 minutes of gameplay. Players' scores start back at zero for each new round. Once all the rounds are completed the Reflector will sum up all the scores. The player with the highest score wins. If there is confusion about what cards do and do not match, the Reflector can reference the Gamification Answer Guide. For those that may require more debate, the Manager will reference the instructor for clarity. The Reaction category is the only category where the matching rules are different from the other categories. For the Reaction category three cards are matched together instead of just two. One card is placed faced up just like the rest of the categories. Participants can then place a single card in the dotted space that matches with the card that is face up. This is not a complete match but a partial match. The participants will then have to place the third card on top of the other two to get a complete match. Any participant can make the complete match, it is not limited to whomever placed the initial second face-up card. Starting with one card face up in the Reaction category, participants can also place two cards down at the same time if they have the two additional matching cards for this category.

3. GpA Example

Fourteen different card topics were developed for the GpA. Seven of these topics were developed into activities, four of which were used in the piloting and implementation period as seen in Table 4: isotope and atomic structure, ionic and covalent naming, molecular geometry, and chemical reactions.

Table 4. GpA Developed Activities

Content Covered in Lecture Curriculum	GpA Topic	Cards
1. Polyatomic Ions and Intro to Acids/Bases *Chapter 3.6-3.11* 2. Covalent Properties & Naming; Naming Practice (all types) *Chapter 4.1, 4.5 and 4.11* 3. Lewis Structures and Molecular Geometry *Chapter 4.2-4.4 and 4.6-4.8*	Naming & Formula	Topic 7-All Categories Topic 3- Reactions Categories
1. Electronegativity, Bond & Molecule Polarity *Chapter 4.8-4.10*	Molecular Geometry & Polarity	Topic 8-All Categories Topic 9-All Categories
1. Balancing and Writing Equations; Intro to Rxn Types *Chapter 5.1-5.2* 2. Double replacement/precipitation/acid-base reactions *Chapter 5.3-5.4* 3. Oxidation-Reduction (Redox) & Net Ionic Reactions All *Chapter 5.5-5.7*	Reactions	Topic 13-All Categories Topic 14-All Categories
1. Chapter 5 review 2. The Mole: Avogadro's Number and Molar Mass *Chapter 6.1-6.2*	Mole, Molar Mass & Stoichiometry	Topic 6-All Categories

3. Stoichiometry; *Chapter 6.3-6.4*		
1. Changes of State - *Chapter 8.1, 8.13-8.14* 2. Intermolecular Forces (IMF) *Chapter 8.2* 3. Gas Laws *Chapter 8.3-8.12 27*	Intermolecula r Forces	Topic 12-All Categories
1. Atomic Structure *Chapter 2.1-2.5* 2. Atomic Structure *Chapter 2.6-2.9*	Atomic Structure & Isotopes	Topic 1-All Categories Topic 2 All Categories
1. Ions, Trends, Binary Naming/Formulas & Properties *Chapter 3.1-3.5, 3.7 and 3.10*	Ions & Electronic Structure	Topic 3-All Categories Topic 5-All Categories

The activities used in the study were selected based on the concurrent content taught in the general chemistry course that week. This example will refer to the activity covering the ionic and covalent naming and can be followed in Figure 3. The Technician distributes five cards to each participant, one card of each category. One card is placed face-up for each category. The example round will be described from the perspective of one participant, Student 1. On Student 1's turn they must determine if there are any matches in their hand for the cards shown on the board. If there are no matches, Student 1 can pull the top card from any category or trade cards with another player. In this example Student 1 has a match in the Application category (blue) between the face up card, the name Copper (II) Bromide, and the formula, $CuBr_2$ (Figure 3, Box 1). Once Student 1 makes the match they pull the top card from the Application category and place it face-up. Then they pull the top card from any category, in this case Student 1 decides to pull from the Reactions category. The other 3 students proceed with their turn. On Student 1's next turn they must determine if there are any matches in their hand compared to what is showing on the board. Since Student 1 has two of the same color category in their hand they check to see if they have any matches in their hand. If there was a match in Student 1's hand, they can set it to the side with the rest of their matches and pull the top card from any category. Student 1 could have done this at any time, but if

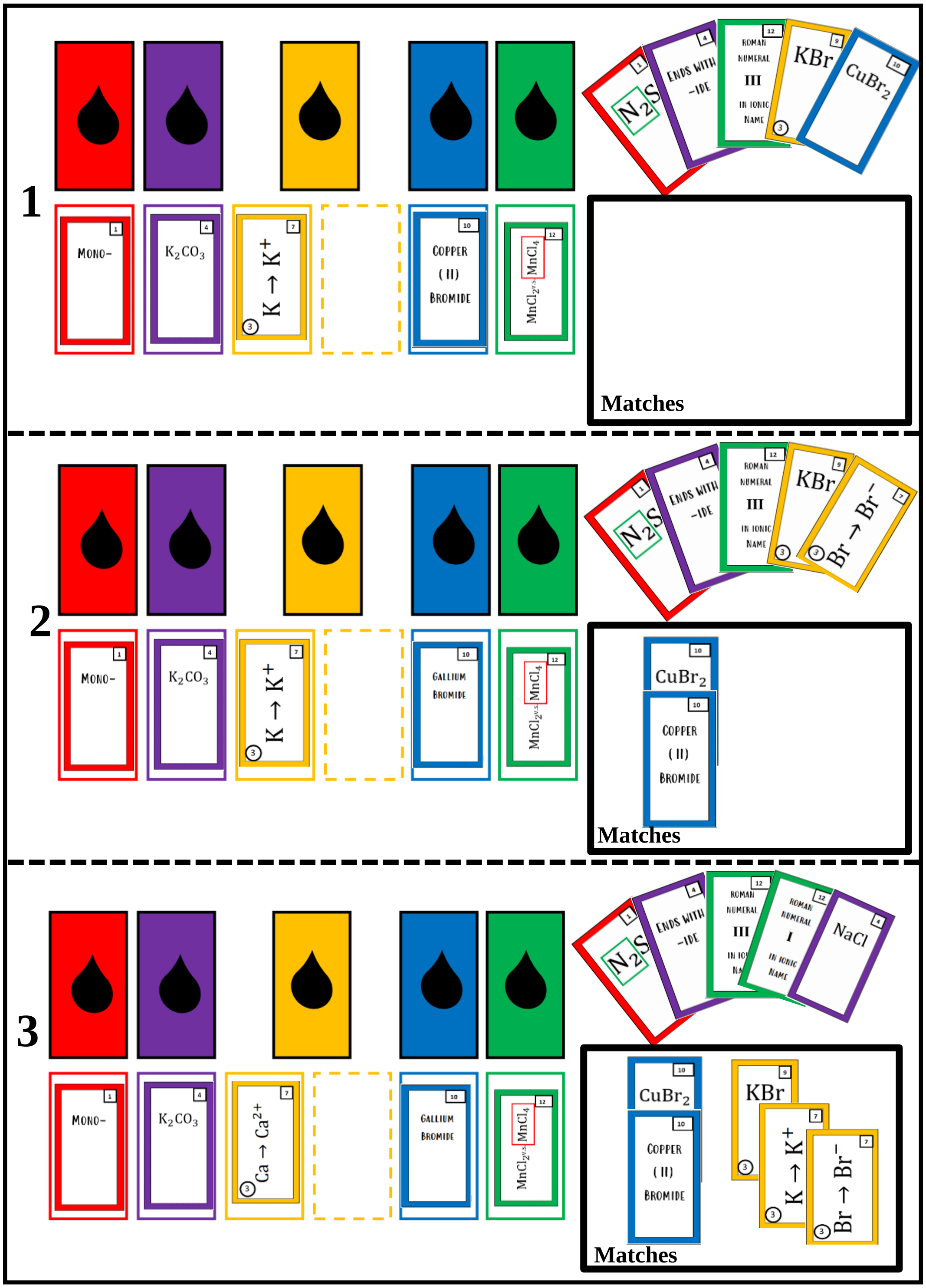

Figure 3. The example gameplay of the GpA card game. Box 1 shows the original gameboard and card deck. Box 2 shows the initial match between the application category while Box 3 shows the match between the reactions category

they do not have a match in their hand, they will need to check the board. On the board

Student 1 has a match in the Reactions category (yellow) between the K^+ ion, the Br^- ion forming the KBr compound (Figure 3, Box 2). Recall for the Reactions category there must be three cards matched. Student 1 sets the match to the side with the other matches, pulls the top card from the Reactions category and places it face-up, and then pulls two cards from the top of any category to place in their hand (Figure 3, Box 3).

Assessment Tools

The control group used in this study was TEL while the experimental groups were GpA and POGIL. POGIL was used as a separate experimental group to ensure that results identified in the GpA methodology were a result of both the gamification and POGIL elements rather than it being POGIL alone. The research study follows a mixed method triangulation convergence model as seen in Figure 4. This means the study

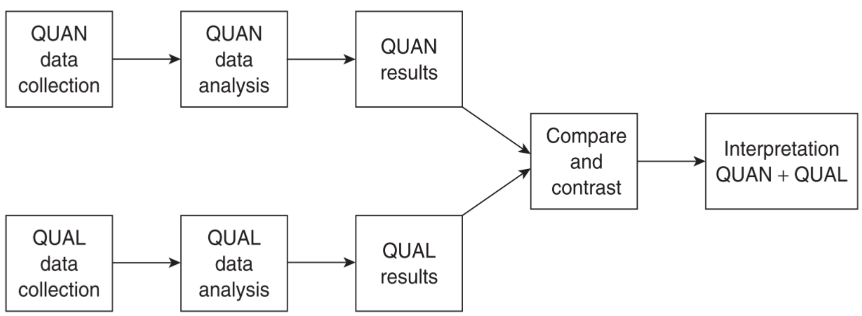

Figure 4. Representation of the mixed method triangulation convergence model

incorporates both qualitative and quantitative assessment tools[77]. The assessments are analyzed separately and are eventually combined to validate the results which are used to develop the final interpretation of the data. The quantitative assessment tools are essential due to the shortage of empirical studies in both gamification and POGIL research. By using quantitative assessment tools with the appropriate statistical power, it can address the short comings in current literature[32, 38, 41, 43, 50]. The qualitative assessments provide clarity into the attitudes and opinions of the students participating in the research study. The following section describes the purpose and use upon which each assessment tool is based. For an understanding on how each assessment tool will be used to answer the research questions and observations see the section titled EXPERIMENTAL DESIGN. All physical examples of the assessment tools can be found in the appendices. The quantitative assessments were as follows: instructor designed demographic survey (ID-DS), instructor designed pre/post-assessment quiz (ID-PPA), test of logical thinking (TOLT), NASA TLX, and statistical analyses. The qualitative assessments were as follows: The Colorado Learning Attitude about Science Survey (CLASS), instructor designed metacognitive survey (ID-MS), post-instruction student interviews (PISI), and an instructor modified gamification questionnaire (GQ).

1. Quantitative Assessments

The ID-DS, appendix F, is a six-item quiz that ask participants to detail basic information including, but not limited to, gpa scores, ACT scores, and year in college. Participant responses are separated based on the teaching methodology they participate in. This information is used to determine if the control group is comparable to the experimental groups. If the descriptive statistics of the gpa and ACT Scores are similar across each teaching group then it is presumed that the control and experimental groups are demographically comparable. This means that the groups are similar enough that it can be assumed the instructional intervention provided had a greater effect on student post assessment performance compared to pre-intervention knowledge. The gpa scores and ACT scores are used in a later statistical analysis to confirm the lack of attrition bias, a common practice in chemical education studies[78].

The ID-PPA, appendixes G and H, is a 15-item multiple choice summative test. It was developed by the principal investigator to measure student understanding of the chemistry content addressed in this study. The assessment is administered twice during each period of the research study, at the beginning of the of the study and at the end of the study. Student assessments are then scored, two points for every correct response with 30 points being the maximum score. The score is then converted into a percentage as seen in equation 14 in Figure 5. Both descriptive and inferential statistics are used to analyze

NASA TLX

(n_y= number of ratings, x_y=average of weighted ratings, y=student ID, specifies students)

$\sum factor\ recorded = factor\ weight$ Eq. 1

$\sum factor\ weights = 15$ Eq. 2

$factor\ weight \times raw\ rating = Adjusted\ Rating$ Eq. 3

$\frac{\sum Adjusted\ Ratings}{15} = Weighted\ Rating$ Eq. 4

$\frac{\sum(n_y \times \bar{x}_y)}{\sum n_y}$=Weighted Average Eq. 5

Test of Logical Thinking

$\frac{x}{10} \times 100 = \%Score$ Eq. 6

$\%Score_{POST} - \%Score_{PRE} = \%Diff$ Eq. 7

$\frac{\%Diff}{\%Scorepre} = \%Growth$ Eq. 8

Metacognitive Survey

(f=frequency, IKWIK=I know what I know, IKWIDK=I know what I don't know, IDKWIK=I don't know what I know, IDKWIDK=I don't know what I don't know)

$\frac{f_{IKWIK}}{Total\ Codes} \times 100 = \%IKWIK$ Eq. 9

$\frac{f_{IKWIDK}}{Total\ Codes} \times 100 = \%IKWIDK$ Eq. 10

$\frac{f_{IDKWIK}}{Total\ Codes} \times 100 = \%IDKWIK$ Eq. 11

$\frac{f_{IDKWIDK}}{Total\ Codes} \times 100 = \%IDKWIDK$ Eq. 12

Student Interview

$\frac{Codes\ are\ the\ same}{Total\ Codes} \times 100 = \%Reliability$ Eq. 13

Pre/Post Assessment Quiz

$\frac{(Correct\ Response \times 2)}{30} \times 100 = \%score$ Eq. 14

$\%score_{POST} - \%score_{PRE} = \%Assesments\ Diff$ Eq. 15

$\frac{\%Diff}{\%Scorepre} = \%Growth$ Eq. 16

Figure 5. List of the equations used for each assessment tool in the data and analysis phase

ID-PPA. For the descriptive statistics the scores are separated based on teaching method and averaged. Assessment differences, equation 15 in Figure 5, are also recorded to determine whether the overall shift in each teaching method was positive, negative, or neutral. The inferential statistics are described in the statistical analysis section.

The Test of Logical Thinking, found in appendix J, is an 18-item multiple choice, short answer test measuring the critical thinking skills of participants. This instrument was developed to measure the modes of cognitive reasoning abilities of students according to Piaget: proportional reasoning, controlling variables, probabilistic reasoning, correlational reasoning and combinatorial reasoning. The distribution of problems are as follows: problems 1 and 2 were proportional reasoning; problems 3 and 4 were controlling variable; problems 5 and 6 were probabilistic reasoning; problems 7 and 8 were correlational reasoning; and problems 9 and 10 were combinatorial reasoning[79, 80]. Problems 1-8 are pairwise multiple-choice questions meaning that each problem is composed of two questions. The first question details a problem-solving question while the second question requires participants to justify their response. Problems 9-10 are short answer questions requiring participants to solve a word puzzle. In scoring, participants only receive a point if they get paired multiple-choice questions correct as well as respond correctly to the two short answer questions. A total of ten points are possible, one point for each correct problem, with scores being converted into percentages as seen in equation 6 in Figure 5. The higher the final score, the higher the participants logical reasoning which, in this study, correlates to problem solving skills. The scores are then used for additional descriptive statistical analysis. Scores are separated based on the teaching methodologies and are analyzed for percent difference and percent growth. The percent difference helps to detail if there is a positive shift or a negative shift in participants TOLT scores while the percent growth details the growth of participant TOLT scores described as a percentage.

NASA TLX, appendix K, is an assessment tool developed by the NASA Ames Research Center that measures the workload of a specific task self-reported by a participant in that task. There are six factors that affect the measured workload of a participant: mental demand, physical demand, temporal demand, performance, effort, and frustration level. Mental demand is how much mental and perceptual activity was required (e.g. thinking, deciding, calculating), physical demand is how much physical activity was required (e.g. pushing, pulling, controlling), temporal demand is how much time pressure is felt due to the rate or pace of the task, performance is how successful the participant thinks they are in accomplishing the goals of the task set by the experimenter, effort is how hard did the participant had to work to accomplish said level of performance, and frustration level is how insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent the participant feels[62]. Each of the factors are compared in a pair-wise comparison. The results of these comparisons are tallied from 0, not relevant, to 5, more important than any other factor, and determines the weight of each factor in later analysis. Each individual factor is then scored on a scale from 0 to 100 in increments of 5. The overall workload score for each participant is computed by multiplying each rating by the weight given to that factor from the pair-wise comparison. The sum of the weighted ratings for each task is divided by 15 (the sum of the weights)[62]. Lastly the weighted average is calculated by taking the number of NASA TLX scores times the average of participant weighted ratings divided by the number of NASA TLX scores as seen in equation 5 in Figure 5. The weighted averages are interpreted using the workload scale as reported by Hart et al. An average of 0-9.9 is low, 10-29.9 is medium, 30-49.9 is somewhat high, 50-79.9 is high, and 80-100 is very high[63]. These interpretations are inferred as the level of cognitive load being experienced by students during the instructional period.

2. Statistical Analysis

As detailed before a major short-coming of gamification and POGIL research is a lack of empirical studies. To address this, inferential statistics have been incorporated in this study to provide empirical research, support the descriptive statistics and support the qualitative assessments used. Due to the sample size limitations and lack of statistical power, nonparametric statistical models were used to analyze data. Four items were analyzed using the inferential statistical models, gpa scores, ACT scores, Pre-Assessment scores, and Post-Assessment scores. gpa scores and ACT scores were analyzed to determine if there were any covariates that were predictors of student performance on assessments outside of the implemented teaching methodologies. Pre-Assessment and Post-Assessment scores were analyzed to determine if there was a statistical difference between the teaching methodologies. The independent variable is the teaching method while the dependent variable is the ACT Score, gpa, Pre-Assessment, and Post-Assessment. Three statistical models were used, Kruskal-Wallis Tests, Dunn Test, and Eta-Squared. All models were analyzed using the RStudio software. The Kruskal-Wallis test is a nonparametric ANOVA equivalent that measures if the medians of two groups are different. The test can be used when a data set is insufficiently homogenous. Like any statistical model, the Kruskal-Wallis test has assumptions that must be met in order for it to be the appropriate model used for a specific data set. The assumptions are as follows:

- Ordinal Variables-the variable in question should be ordinal or continuous (i.e. have some kind of hierarchy to them)
- Independence- Independent variable should consist of two or more categorical, independent groups that have no relationship
- Sample size – each group must have a sample size of 5 or more. With a sample size in this range, the chi-square distribution well-approximates the H statistic.

The Kruskal-Wallis Test incorporates an H-Test test statistic tested at an alpha value of 0.05 (α=0.05). The null hypothesis is the k distributions are identical, the medians (mean on ranks) are equal across the samples while the alternative hypothesis is that at least one of the population medians differs from the rest. If the p-value is greater than 0.05 ($p>0.05$) then there is a failure to reject the null hypothesis meaning that there is not a statistical difference between variables. If the p-value is less than 0.05 ($p<0.05$) then the null hypothesis is rejected meaning that there is a statistical difference between variables. Rejecting the null hypothesis results in the use of a post hoc test, which is used to determine where the statistical difference lies. In this study, the Dunn's Test was used for post hoc analysis. The Dunn's Test can be used to pinpoint which specific variables are significant from the others; it is the nonparametric alternative to the Tukey's Test which is the post hoc test that would have been used with ANOVA. The test utilizes a Z-Test test statistic at an alpha value of 0.05 (α=0.05). The null hypothesis states there is no difference between groups (groups can be equal or unequal in size). The alternative hypothesis states there is a difference between groups. If the p-value is less than 0.05 the null hypothesis is rejected, meaning there is a difference between groups. If the p-value is greater than 0.05 then there is a failure to reject the null hypothesis meaning there is no difference between groups. Effect size is a number measuring the strength of the relationship between two or more variables in a population; the larger the effect size the stronger the relationship between two variables. The specific effect size used is Eta Squared where 0.01 is a small effect size, 0.06 is a medium effect size, and 0.14 is a large effect size. Eta Squared is reported as x% of variability in the dependent variable able to be explained by the independent variable.

3. Qualitative Assessment

The Colorado Learning Attitudes about Science Survey (CLASS), appendix L, is a 50-question Likert scale survey measuring participant's attitudes about science, specifically physics and chemistry[81, 82]. Each of the 50 questions are organized into nine categories: Personal Interest, Real World Connections, Problem Solving General, Problem-Solving Confidence, Problem Solving Sophistication, Sense making effort, Conceptual Connections, Conceptual Learning, and Atomic-Molecular Perspective of Chemistry[81, 83]. The student responses are on a Likert scale of 1 to 5 with 1 being strongly agree and 5 being strongly disagree. The scale is an ordinal scale meaning it assumes there is not an equal difference between each possible response; therefore, scoring must be represented as a percentage of agreement[81]. In order for the CLASS survey to be analyzed, students must complete the survey pre-activity and post-activity. This allows for the survey to take the favorable and unfavorable responses and synthesize them into either expert, neutral or novice shifts. Scoring is done by determining, for each student, the percentage of responses for which the student agrees with the experts' view ('percent favorable') and then averaging these individual scores to determine the average percent favorable, the same is done for unfavorable responses[81]. Neutral scores are when the student neither agrees nor disagrees with the expert.

The ID-MS, appendix E, is a 10-item summative assessment that includes 5 multiple choice questions paired with five Likert scale questions asking students to rate their confidence level (5 high to 1 low). Metacognition refers to knowledge about one's own thoughts and cognitive process as well as the cognitive regulation involved in directing one's learning[84]. Learners assess and monitor their learning by reflecting on their performance[84]. There are two aspects to metacognition, cognition knowledge and cognitive regulation. Cognitive knowledge involves the learner and factors affecting their cognition, how learning works, learning strategies to manage one's own cognition, and when to use a given learning strategy[84, 85]. Cognitive regulation assesses the task, plan for and use of appropriate strategies and resources, monitoring of task performance, evaluating processes and products of student learning and revision of goals and strategies accordingly[84, 85]. The ID-MS was implemented after each teaching intervention session. Each group of multiple-choice questions were adapted based on the content taught during the teaching intervention. The ID-MS measures student metacognition in two ways; the 5 multiple choice questions measure student understanding of content while the Likert scale measures student confidence in their understanding. The multiple-choice questions changed based on the lesson being taught. Student responses were separated based on teaching methodology and then coded as seen in Table 5.

Table 5. Codes used during metacognitive survey

Answer Responses	Likert Scale	Interpretive Code	Metacognition
Correct	4-5	Positive Result, Intervention and Student learning	I know what I know
Correct	3	Neutral Result, Student Pre-conception	I don't know what I know
Correct	1-2	Positive Result, Intervention	I don't know what I know

Incorrect	4-5	Negative Result, Misconception and Intervention	I don't know what I don't know
Incorrect	3	Neutral Result, Misconception	I don't know what I don't know
Incorrect	1-2	Negative Result, Misconception, Student Pre-conception	I know what I don't know

The codes were based on the responses to the multiple-choice questions as well as the Likert questions. There were four codes that were developed:

- I know what I know (IKWIK)
    - Refers to students who respond correctly to a multiple-choice question and responded a 4 or higher on the Likert scale.
- I know what I don't know (IKWIDK)
    - Refers to students who responded incorrectly to a multiple-choice question and responded a 2 or lower on the Likert scale.
- I don't know what I know (IDKWIK)
    - Refers to students who responded correctly to a multiple-choice question and responded a 3 or lower on the Likert scale
- I don't know what I don't know (IDKWIDK).
    - Refers to students who responded incorrectly to a multiple-choice question and responded a 3 or higher on the Likert scale

The codes were interpreted to help explain the current metacognitive state of the students after each teaching intervention. Students who land within IKWIK and IKWIDK are in a positive metacognitive state because it is easier to address misconceptions when students are aware of what information they do and do not know. IDKWIK is a neutral metacognitive state, although students accurately know the content it is not guaranteed they understand why or how. This can potentially lead to the development of misconceptions later on. IDKWIDK is a negative metacognitive state as students do not understand the content taught and have greater potential to produce misconceptions. Once all responses are coded, they are separated based on the teaching intervention as well as the teaching methodology. A sum of the codes is used to analyze the results. From this analysis a percentage is calculated, as seen in Figure 5, by taking the individual codes and dividing each by the total codes.

Two types of interviews were utilized during this study, post-instruction student interviews and a gamification questionnaire. The post-instruction student interview (PISI), appendix N, is a 9-item short answer interview and was developed by the principal investigator to determine student attitudes and experience during each teaching methodology. The students were given the interview as a free response prompt distributed after the last instructional period. Each response was separated based on teaching methodology and categorized based on the pre-developed interview codes as seen in Table 6, developed during the initial piloting period of the study.

Table 6. Interview codes used to analyze student responses

Code	Definition
Clear Understanding	Students express secure understanding, simplicity, and confidence in knowing the content or topic
Unclear Understanding	Students' express confusion, a lack of understanding, difficulty or frustration with the content or topic
Student Active Interactions	Students describe working together in groups, working in which they apply information, or describe the learning process in which they build on knowledge
Student Inactive Interactions	Students describe working alone, apply only information that was given and not describing how information builds on one another
Zeal	Students express excitement, a sense of feeling, and positive adjectives describing experience
Lack of Zeal	Students express disappointment, dread, and negative describing experience

Effect of Past Experiences	Students describe work they've done in the past, most likely high school or a previous chemistry course
Edits to Game	Students describe ways to modify the gamified activity

The gamification questionnaire, appendix M, was a 6-item multiple choice survey adapted from a study by Triboni and group[72] to assess student opinions about the gamification activity. The questionnaire was administered simultaneously with the PISI but only to the students participating in the GpA teaching methodology.

Experimental Design

This study incorporates a quasi-experimental design with a mixed method triangulation convergence model. As described in the ASSESSMENT TOOLS section, the triangulation convergence model incorporates both quantitative and qualitative assessment tools. These tools follow the assessment triangle to clarify student understanding. The assessment triangle includes three parts[1, 77]:

- Observation-assessment items and their potential student responses, determined by beliefs about the sort of prompts or situations likely to elicit useful evidence of students' knowledge and skills.
- Interpretation-to interpret assessment-derived data, one must have a well-developed sense of what inferences these data support, we must be able to take the data from an assessment and use it as evidence to support the argument that students are developing some aspect of the desired cognition.
- Cognition- represents a theory about how students develop expertise in a domain

To develop the experimental design, clear objectives were composed based on each of the research questions paired to the study. Each objective had an experimental approach and assessment tool paired with it from which the overall experimental design was composed as seen in Table 7. The first research question, the impact of GpA on various metrics, was

Table 7. Research objectives according to the research questions

Research Question	Objectives	Experimental Approach	Assessment Tool
What is the impact of GpA on student academic performance, conceptual understanding, and engagement	Conduct a piloting study of the gamified POGIL methodology	Observing whether it is possible to effectively gamify 3-6 POGIL activities	Gamification Questionnaire (GQ)
	Analyze Student's short-term academic performance	Students complete pre and post activity quizzes to determine whether their score is increasing or decreasing	Kruskal-Wallis, Pre/Post-Quiz, CLASS
	Analyze Student's engagement	Students complete gamified POGIL activities and compare results against control group	CLASS, Student Interview
How does GpA effect small group interaction & problem-solving skills?	Analyze student's cognitive load in relationship to their group participation	Students complete GpA in comparison to control group	NASA TLX, CLASS, Gamification Questionnaire
	Analyze student's problem-solving skills in relationship to their performance	Students complete pre and post activity quizzes to determine whether their score is increasing or decreasing	TOLT, Metacognitive Survey

composed of three objectives: GpA piloting, assessment of short-term academic performances, and student engagement.

The second research question, GpA effects on group interactions, was composed of two objectives: analysis of cognitive load's relationship with group participation and analysis of problem-solving skills in relationship to student performance.

With the objectives having been written and the GpA having been developed the experimental approach was drafted to address each research question. The study was conducted in three periods: piloting, implementation, and a second implementation. Each period took approximately 1-2 semesters. The piloting period provided an opportunity to validate each teaching methodology and assessment tools while the implementation methodologies provided an opportunity to make clear assessments and comparisons of the teaching methodologies. More information on the periods is described in CHAPTER 4: RESULTS AND ANALYSIS. During each semester teaching interventions were used where a group of students would meet together with a research assistant once a week for seven weeks. The teaching interventions ran in tandem with the primary lecture course and was used to assess each teaching methodology. During the seven weeks there were two weeks of recruitment, one week of introductory surveys, three weeks of instruction, and one week of conclusion surveys. The pre/post-assessment instructional method was adapted from both POGIL and gamification research conducted by Gogal and group[73], Putz and group[7], and Vincent-Ruiz and group[23]. The population studied across the entire research study were first, second, and third-year undergraduate students in undergraduate level chemistry courses, specifically general chemistry (CHEM 106 and 112) and introductory level biochemistry/organic chemistry (CHEM 108). Recruitment strategies were consistent from the piloting to the implementation periods except for the addition of incentives in the implementation phase. During the implementation phase students were offered a financial incentive to participate in the research intervention ($5 per lesson with a maximum of $15). Students were recruited using an open-recruitment convenience sampling method. Emails were sent out to the students every three days for a two-week period and the primary instructor of the chemistry course announced to the students an opportunity to participate in the study during their reserved lecture time. Students who were interested in participating signed up using an online survey and reserved one of three available times to participate. The time that the students signed up for was the time they would attend the intervention. The intervention was once a week for four weeks. The teaching methodology that would be used in the intervention time-period was pre-arranged and not told to the students until the first day of the intervention. Quasi-experimental research design is common in DBER and was used in this study based on an experimental design by Anthony Chase. Chase and group implemented a quasi-experimental design for a POGIL implemented study in which all of their students were enrolled in a large lecture course and participated in a non-lecture discussion group. The study used two different settings, 1st semester general chemistry and 1st semester organic chemistry.

In a similar way, this present GpA study implements a sperate intervention group from the large lecture course. The control group was the intervention group taught using TEL while the experimental groups were the intervention groups taught POGIL and GpA individually. Once the students were signed up for one of the intervention groups they would attend the introductory survey session. During this session students would sign the IRB Consent form, appendix A, and complete all of the introductory surveys: ID-DS, CLASS, TOLT, the pre ID-PPA. The research assistant would explain to the students the teaching methodology and how they were expected to participate. After the introductory sessions the students participated in the teaching intervention over the next 3 weeks. Each intervention was taught by the same research assistant. The lessons taught during the intervention changed week to week to match with what the students were being taught in the lecture course. During the GpA sessions students would take the first 5 minutes to work through the exercise problems in the activity. Next students would alternate between 5 minutes of gameplay and 5 minutes of answering critical thinking questions for 55 minutes. Lastly students would complete the lesson specific ID-MS and the NASA TLX survey. During the POGIL sessions students would spend 55 minutes completing the given POGIL activity and completed the lesson specific ID-MS and the NASA TLX survey. During the TEL sessions students would have a 30-40 minute lecture along with a

15-25 minute practice problem review and complete the lesson specific ID-MS and the NASA TLX survey. During the last week of the intervention students would complete the conclusion surveys: CLASS, TOLT, the post ID-PPA, PISI, and GQ (only done by the GpA group).

CHAPTER 4: Results and Analysis

Semester Interventions

As described in the experimental design the research study was conducted in three periods: piloting, first implementation, and a second implementation. Though the intervention itself remained consistent throughout the study, each period offered an opportunity to make necessary edits and adaptations. During the piloting period researchers seek to validate the teaching methodologies and ensure the assessment tools function properly. In order to properly compare each teaching methodology, it is vital to ensure that the students understand their roles and that the instructor properly implements the teaching method. If the teaching methods are improperly implemented, then there is no guarantee that the resulted reported are a result of the methodologies. Assessment tools are also tested during the piloting period to ensure that the students know how to use the assessment tools and that Instructor Designed tools function as intended. This confirms that each assessment tool reports and predicts data as intended. The teaching methodologies were validated by setting specific goals for each method. If the methodology reached these goals, then it can be inferred the methodology was properly implemented. The goals were developed based on teaching interventions described in chemistry education literature and are mainly based on students understanding their role and responsibilities in each teaching methodology:

- TEL
    - Students actively take notes
    - Students participate in problem solving activities
- POGIL
    - Students communicate with their partners
    - Students complete the critical thinking questions in the activity
    - Students actively manage their group role and take responsibility for their tasks
- GpA
    - Students participate in the gamification activity
    - Students manage their group role and communicate with their partners
    - Students work actively together to collaborate on the lessons

The teaching methodologies were validated based on instructor observation and student responses to interview questions. At the end of the piloting period, the results of the teaching methodology and assessment tools were reported. Any major or significant errors are corrected and adapted for the implementation periods. The implementation periods are quite similar, the main difference between the two is that minor changes to the teaching methodologies and assessment tools used can be made during the first implementation period. The changes can only be minor, if major changes are necessary then it is important for the study to return to the piloting phase.

1. Piloting Period Spring 2021

The piloting period was conducted during the Spring 2021 semester at a local medium-sized midwestern university. The piloting period was conducted over a single intervention day to validate each teaching method used in future parts of the study. Students were recruited from the undergraduate general chemistry survey course, CHEM 106, via email as well as in class announcements for two weeks. Students then used an online survey to designate what time frame worked best for their schedule. Once the two-week period ended, student time frames were tabulated to determine what two-hour period allowed for the largest population of students to attend. Four sections, date and time periods, were identified. Each section had a predetermined teaching methodology that would be used. Once that time was identified students were emailed the research consent form as well as the date, time, and location in which the research study would take place. Students who were not able to attend their original section were given the opportunity to attend a section scheduled later. During each section students were given 2 hours: thirty minutes were dedicated to completing the introductory surveys, the next hour was dedicated to participating and completing the lesson on atoms and isotopes using the designated teaching methodology, and the last thirty minutes were dedicated to completing the conclusion surveys. The assessment tools used during the piloting period were the ID-DS, TOLT, CLASS, ID-PPA, and the PISI and GQ (GQ was completed only by students who participated in the GpA section). The PISI and GQ were used to validate the teaching methodologies and measure student attitudes towards their session's specific methodology. Both interview surveys are used to validate two things: teaching methodology goals and student attitudes. The teaching methodology goals were stated earlier in this chapter, the PISI and GQ are used to record if students were able to identify their responsibilities based on participation in the teaching methodology. The PISI and GQ are also used to determine if the teaching methodologies result in students having similar attitudes towards science as have been previously reported in literature.

2. First Implementation Period Fall 2021-Spring 2022

The first implementation period was conducted during the Fall 2021 and Spring 2022 semesters. Unlike the piloting period, the implementation period was conducted over five-weeks per semester. During that five-week period students participated in an introduction session for one week, teaching sessions for three weeks, and a conclusion session for one week. Students were recruited using convenience sampling from three first- and second-year undergraduate chemistry classes, CHEM 106 (General Chemistry Survey), CHEM 108 (Organic and Biochemistry Survey), and CHEM 112 (General Chemistry I). The research assistant of the intervention sessions attended the chemistry lecture sections and announced to students how to sign-up for the intervention sessions, emails were also sent out sent to students guiding them on how to sign-up. This took place during the first two-weeks of the semester. After the two-week period ended students attended the introduction sessions where they learned about the teaching method used in the intervention sessions as well as completed the pre-intervention (or introductory) surveys. Those surveys were the same as in the piloting study, the ID-PPA, ID-DS, TOLT, and CLASS. Along with these assessments two new assessments, NASA TLX and ID-MS, were incorporated into the implementation period. NASA TLX provided the research assistant with a deeper understanding of the amount of cognitive load being experienced by the students. The ID-MS provided the research assistant with a clearer understanding of the student's immediate understanding of the chemistry content. Since the teaching methodologies were validated in the previous experimental period, later explained in the DATA AND ANALYSIS section, the NASA TLX and ID-MS were implemented because the results measured in the two assessment tools had a higher possibility of being correlated to the teaching methodology itself instead of another covariate. They were not used in the original piloting study because of the length of the study and insecurity on the validation of the implemented teaching methodologies. The introductory session was used for students to complete the introductory surveys. Students then returned the following week for the first lesson in the intervention session. Similar to the piloting study there were three different intervention sections taught during the week. Each section had a different, predetermined teaching methodology used. Students participated in 55 minutes of supplemental instruction and completed the two surveys, NASA TLX and ID-MS, at the end of each lesson. During the piloting period the lesson centered around atomic structure and isotopes, however, during the implementation period three new lessons were used centering around ionic and covalent naming, molecular geometry, and reaction types. In the final week of the research intervention student completed the conclusion surveys. These were three of the surveys completed during the introduction session, the ID-PPA, TOLT, and CLASS, as well as two additional assessments, the GQ and the PISI. In both semesters, a second recruitment period during the mid-term of the semester was conducted in order to increase the sample size of the study. The data from the piloting period and the implementation period were combined and analyzed to determine the possible trajectory of the study and the necessary changes.

3. Second Implementation Period Fall 2022

The second implementation period was conducted over the Fall 2022 semester at the same local mid-western university. Same as the first implementation period, the second implementation period replicates the assessments, recruitment approaches, and teaching methodologies. The main difference between the two implementations is the second implementation period recruited only from the CHEM 106 course and the timeline was expanded to include the first 10 weeks of the semester, different from the first 5 weeks of the semester for the first implementation period. Student recruitment took place over the first 5 weeks of the semester using email and in-person recruitment. By expanding the recruitment timeframe, it was proposed that a greater sample of students would seek supplemental assistance for the lecture thus increasing the sample size. Introductory surveys were completed the next week followed by three weeks of teaching interventions and one week of conclusion surveys. In both the first and second implementation periods, students were provided with the same incentives for completion of the study.

Results and Discussions

A total of 69 students participated in the research study with a 46% retention rate. That means from all the students who expressed interest in participating in the study, 46% of those students were retained and completed the study.

Table 8. Demographic Survey Year and Major

	Year (n)				Major (n)			
Teaching Group	1st	2nd	3rd	4th	Nursing	Ag	Environmental Studies	Other
GpA	19	5	0	1	15	5	2	3
TEL	16	4	1	1	11	7	3	1
POGIL	11	6	5	0	11	5	1	5

Most of the participants were first-year white female nursing majors as seen in Tables 8 and 9. This is one of the limitations in the generalizability of the results in the study which was the lack of diversity amongst the sample group compared to the intended population. All of the group data was combined based on the teaching group the students participated in. The only data that was separated and analyzed based on the research period was the student interviews. The interviews from the piloting study were analyzed individually to validate each of the teaching methodologies. Otherwise, all other data was grouped together based on teaching methodologies. The data was analyzed using a mixed-method triangulation model. This model allowed for the researchers to essentially answer each research question individually by analyzing the qualitative and quantitative data individually then combining them together. Using the ACT scores and gpa from the demographic survey, researchers were able to determine whether or not each teaching group was comparable. If there was a statistical difference between the teaching groups, then the presumption could be made that the teaching methodologies were not the sole predictor or influence on the student's assessment performances in the research study. Both the descriptive and inferential statistics were observed to determine the final results as seen in Table 10.

Table 9. Demographic Survey Gender and Race

	Gender (n)		Race (n)					
Teaching Group	Male	Female	White (Non-Hispanic or Latino)	Black/African American	Hispanic or Latino	American Indian/Alaska Native	Asian	Prefer not to say
GpA	4	21	23	0	2	0	0	0
TEL	6	16	19	1	0	0	1	1
POGIL	6	16	19	1	0	1	1	0

Table 10. Teaching methodologies averages and statistical results

Group	Mean	Kruskal-Wallis Test	Eta Effect Size	95% Confidence Level
ACT	GpA 20.90 TEL 23.05	$F(2,63)=4.980$, $p=0.083$	0.0550	GpA [19.293, 22.515] TEL [21.254, 24.846]

	POGIL 22.41			POGIL [20.946, 23.872]
gpa	GpA 3.37	$F(2,69)=1.013$, $p=0.603$	0.0069	GpA [3.123, 3.613]
	TEL 3.41			TEL [3.18, 3.644]
	POGIL 3.49			POGIL [3.204, 3.778]

Observing the descriptive statistics there is no significant difference between the mean values of the ACT scores and gpa of each teaching group. Using the Kruskal Wallis Test and eta effect size the presumptions from the descriptive statistics are confirmed with there being no statistical difference between the teaching groups. Both scores reported a p-value greater than the recorded alpha value of 0.05 ($\alpha<0.05$). According to the effect size both the ACT and gpa reported to have small effects on the teaching methodologies, ACT reported to explain 5.55% of the variability in the teaching methodologies while gpa reported to explain 0.69% of the variability in the teaching methodologies. Further analysis on the data set can be made under the assumption that the teaching methodologies had the greatest effect on student performance in the assessments since neither of the scores (ACT or gpa) reported in the demographic survey revealed any statistically significant differences between the teaching groups. Based on the statistical results of the demographic survey further analysis was completed to determine the results of the two research questions:

(1) What is the impact of GpA on student academic performance, conceptual understanding, and engagement?

(2) How does GpA effect small group interaction and problem-solving skills?

Though the triangulation convergence model allowed for the individual analysis of the qualitative and quantitative data, it also allowed for the combination of the data for final interpretation. In answering the first research question the quantitative data used was the ID-PPA while the qualitative data used was the CLASS, PISI, and GQ. In answering the second research question the quantitative data used was the NASA TLX and TOLT while the qualitative data used was the CLASS, GQ and ID-MS.

The ID-PPA provided a clearer understanding of the actual academic performance of students before and after the introduction of the teaching methodology while the CLASS, PISI and GQ provide clarity in student self-perception on their performance and attitudes after the introduction of the teaching methodology. Table 11 reports the initial pre-assessment and post-assessment for each teaching methodology while Table 12 reports the statistical analysis of each assessment for each teaching methodology.

Table 11. Summary of Assessments for Teaching Methods (n=61)

Teaching Group	Post-Assessment	Pre-Assessment	%Growth
GpA	62.56	43.90	42.53
TEL	73.37	53.85	36.24
POGIL	69.35	56.98	21.70

Observing the descriptive statistics students participating in the POGIL group had the highest pre-assessment score while the TEL group had the second highest pre-assessment score. The GpA group had the lowest scores amongst each teaching group with an average significantly lower than that of the other two teaching methodologies. Using the Kruskal-Wallis test to determine if there is a statistically significant difference it was found that at least one of the median values from the teaching groups differed from one another with the p-value less than the alpha value ($0.026<0.05$).

Table 12. Statistical Analysis

Group	Kruskal-Wallis Test	Eta Effect Size	95% Confidence Level	Dunn Test
Pre-Assessment	$F(2,69)=7.287$, $p=0.026$	0.1058	GpA [37.456, 50.334] TEL [45.025, 62.679] POGIL [52.028, 61.932]	GpA-POGIL Z=-2.715, p=0.019
Post-Assessment	$F(2,61)=2.873$, $p=0.237$	0.0548	GpA [52.957, 72.167] TEL [66.896, 79.842] POGIL [60.975, 77.715]	

The Dunn's test was used to determine which teaching groups reported the significant difference between one another and it was found that GpA and POGIL had the significant difference. This was expected as being a possibility between the teaching groups in the post-assessment but was an unexpected result in the pre-assessment of the ID-PPA. In the pre-assessment students did not have any exposure to the teaching methodologies meaning that some other factor was responsible for the significant difference reported between the teaching groups. One explanation of the statistical difference is the low performance of the GpA methodology in comparison to the other two teaching methodologies, both which had comparable mean values in the pre-assessment scores. Since neither the ACT or gpa scores functioned as covariates, an analysis in student pre-assessment performance according to major was conducted. However no statistical difference was shown between the majors (Nursing μ=52.29, Ag μ=48.37, Environmental Studies μ=45.55, Other μ=56.13). Unlike the pre-assessment of the ID-PPA, the post-assessment reported no statistical difference between each teaching group. The descriptive statistics showed reversed results between the mean values of the teaching groups with TEL having the highest post-assessment score and POGIL having the second highest. The GpA teaching methodology had the lowest post-assessment score but the final results amongst all groups was comparable and not statistically different. Since the pre-assessment reported a statistical difference, ANCOVA was used to analyze the remaining quantitative assessments with the pre-assessment scores used as a covariate. To further understand the short-term academic performance the %growth was reported for each teaching methodology using the calculations described in Figure 5. By reporting the %growth this provides clarity on the improvement in assessment performance for

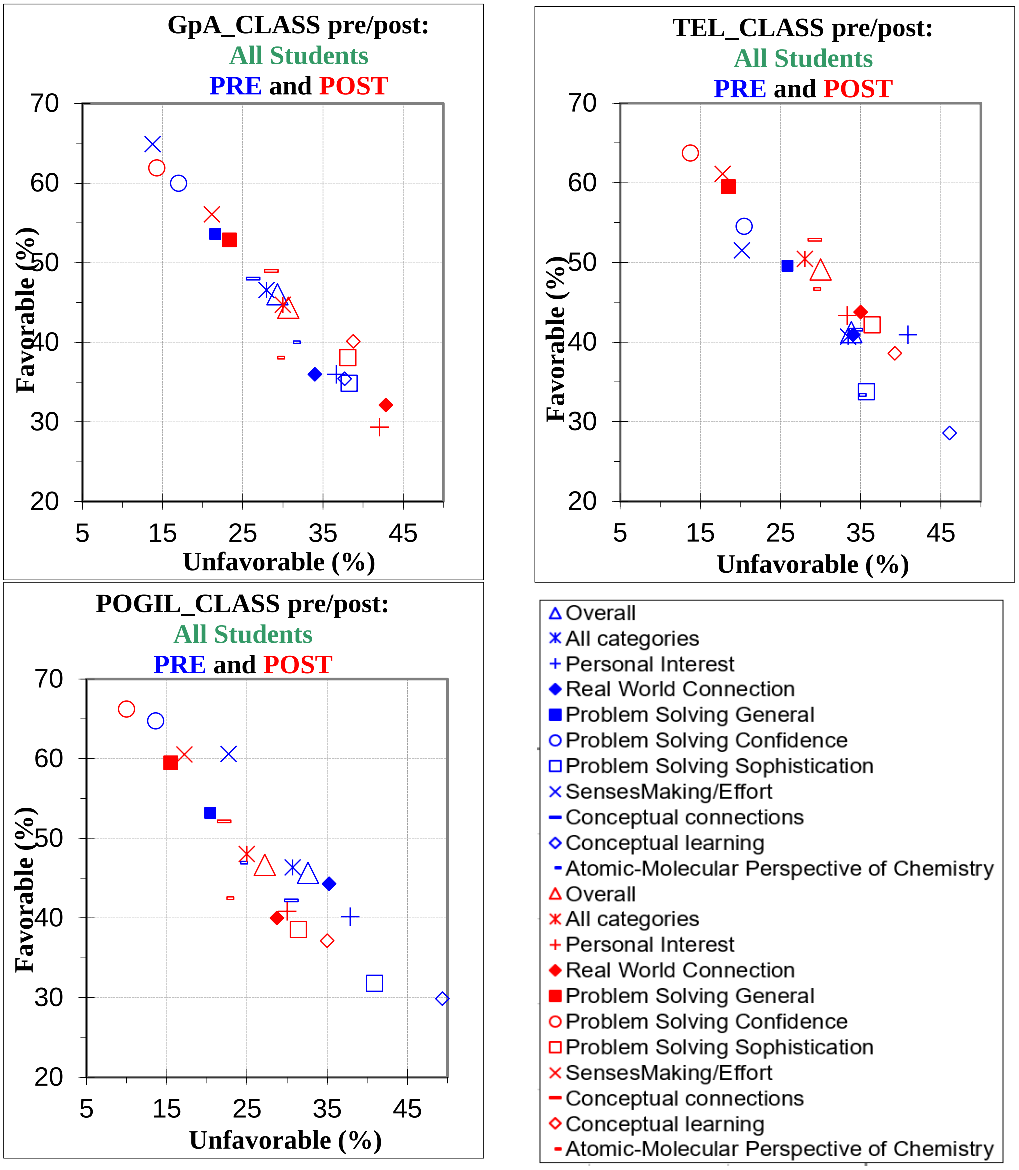

Figure 6: The graphical representation of the CLASS results from each teaching group. The bottom right legend details the categories each symbol represents. The blue symbols come from the students' CLASS responses prior to the introduction of the teaching methodology while the red symbols come from the students' CLASS responses after introduction to the teaching

each teaching methodology. GpA reported the highest improvement with TEL reporting the lowest improvement. Why did the GpA perform quantitively so much lower than the other two teaching methodologies yet show a higher level of improvement compared to the other teaching methodologies? One of the main reasons deals with the conceptual understanding of the content held by the students in each teaching methodology a well as the students' level of engagement. Figure 6 details the participant responses to the CLASS which measures students' attitudes towards chemistry before and after the implementation of the respective teaching methodologies to their group. Student responses to each question are calculated and combined, based on each category, into two values, favorable and unfavorable. The terms of favorable and unfavorable were determined based on the participants' responses to the survey were in agreement with the predetermined expert view. Agreement with the expert is favorable while disagreement is unfavorable. The values are then plotted based on category with the favorable value as the y-axis and the unfavorable value as the x-axis. Students' overall attitudes were reported as having a novice, neutral or expert-like shift based on comparing responses between the pre and post surveys. Novice shifts are students having a decrease shift in favorable responses and an increase shift in unfavorable responses. Neutral shifts are students having both an increase or a decrease in favorable and unfavorable responses. Expert shifts are students having an increase shift in favorable responses and a decrease shift in unfavorable responses. Of the nine categories in CLASS, six are relevant in analyzing student academic performances and motivation: Personal Interest, Sense Making Effort, Real World Connections, Conceptual Connections, Conceptual Learning, and Atomic-Molecular Perspective of Chemistry.

By working together in larger groups rather than alone, students are able to verify their understanding of the chemistry content. However, there is comparable conceptual understanding between the TEL and the guided inquiry learning methodologies (GpA and POGIL) which incorporate group learning. A consensus into why deals with student focus in the type of group that they are participating in. Working in a group alone does not provide students with clarity in their conceptual understanding. Instead, it must be a group with clearly defined roles and clarity in their previous understanding of the content. Quoting one of the participants of the study: S22052- “While I feel that with the group I had it was helpful in other groups it could be worse. Dependent on the people and how much work they put into helping each other and learning the material it could most definitely be detrimental or confusing”. According to the CLASS both the POGIL and GpA resulted in expert or neutral shifts in student attitudes towards their conceptual understanding. However, in categories relating to student interest and motivation, the GpA methodology resulted in novice shifts in student attitudes. The group work mechanic helps students in their conceptual understanding of the content, but the gamification mechanic does not provide any benefit to the students’ motivation or interest. Part of this has to deal with the students’ familiarity with the teaching mechanic as seen in Table 13.

Table 13. Gamification Questionnaire (n=21)

Question	Response	Frequency
How Frequently do you play card games and/or tabletop games	<1 time per week	18
	2-3 times per week	2
	6+ times per week	1
What was the relevance of playing the Gamified POGIL Activity	I learned new concepts with GpA	9
	GpA clarified concepts that I already learned	10
	GpA didn’t teach or clarify any concept	2
How was the gaming experience	I enjoyed the GpA and it helped learn/clarify chemistry concepts	16
	I didn’t enjoy GpA, but it did help me clarify chemistry concepts	3
	I didn’t enjoy GpA and it didn’t help learn/clarify chemistry concepts	2
How easy was it to learn the game and game mechanics	It was hard to learn GpA rules but the game mechanics are interesting	7
	It was fairly easy to learn GpA rules and the game mechanics are interesting	12
	It was hard to learn GpA rules and the game mechanics are too complicated	2
If GpA were commercially available, would you buy it or want your professor to use it?	Yes	13
	No	8

A lack of familiarity with the responsibilities or roles in the teaching methodology results in a lack of motivation or interest on the part of the student. There can be a recorded interest in the game activity itself but that does not result in interest or motivation in the chemistry content. This is seen in comparing the gamification questionnaire results with the CLASS results. When it came to the self-perception on their conceptual understanding GpA students found the teaching methodology helped teach or clarify their understanding, similar to the neutral shift in the conceptual understanding categories of the CLASS. At the same time, students in the GpA found the gamification mechanics of the GpA difficult to understand and grasp, similar to the novice shifts in the interest categories of the CLASS. Though the students were engaged in the teaching process, the main source of engagement was a result of the group work mechanics in the GpA and less a result of the gamification mechanics. Yet at the same time, students had predominately positive perceptions of the gamification experience in the GpA. Despite performing worse quantitatively compared to the other teaching methodologies, participants in the GpA methodology reported predominately positive experiences qualitatively in reference to their performance and engagement. Under the GpA teaching methodology student self-perception on their conceptual understanding was higher compared to the TEL and POGIL teaching methodology. The student interviews in Table 14, reported with 71.62% inner-coder reliability, show the overall self-perception of the

Table 14. Frequency of student interview responses in each code (n=61)

Code	Clear Understanding	Unclear Understanding	Student Active Interactions	Student Inactive Interactions	Zeal	Lack of Zeal	Effect of Past Experiences
GpA	18.90%	14.28%	24.36%	7.98%	11.76%	5.88%	16.80%
TEL	10.34%	14.48%	21.37%	15.17%	11.03%	15.86%	11.72%
POGIL	7.69%	10.05%	31.36%	18.93%	8.87%	8.87%	14.20%

participants in each teaching methodology. As students interacted more with their respective teaching methodologies, their self-perception of both engagement and conceptual understanding began to develop. Participants in a non-active learning environment were more likely to have a self-perception of disinterest in the learning environment (lack of zeal) as well as seeking a learning environment that is disengaged from group learning. Students in an active learning environment were more likely to have a self-perception of a clearer conceptual understanding as well as incorporating group-based activity in the learning environment. However, responses in the GpA differed from the POGIL group in that their self-perception of their conceptual understanding did not correlate with their actual performance. The gamification mechanic provided students with engagement and interest into the learning environment, however, it did not provide adequate support for students to verify their conceptual understanding with their group. Instead that took place during the POGIL-style question and answer portion of the GpA teaching methodology. Assessing interviews students in the GpA had a similar consensus, although the group work mechanic of the teaching methodology was helpful, the gamification mechanic was either neutral in effect or confusing and distracting as observed in two participant quotes below:

> S21040-"I have never had a gamified experience in a class and it helped my learning process by discussing any confusing concepts or anything I was unsure about. It helped my learning process rather that making it worse, so I think it was a good tool to use to help me review concepts. I feel like discussing old concepts is a great refresher especially because things are just adding onto one another."

S22002-“Sometimes these experiences are helpful however sometimes they can be very distracting and detrimental to my learning experience. In certain situations I think they are beneficial and in others I find them annoying.”

The reported results on gaming experience and future implementation of GpA in Table 13 show a majority of the GpA students have neutral or favorable attitudes towards the methodology itself. Attitudes towards chemistry, however, saw no overall improvement. This result can potentially be explained by examining the second research question, which analyzed the problem-solving skills and cognitive effects of the teaching methodologies on the respective participants.

The problem-solving skills of each teaching methodology were comparable as seen in Table 15 and Figure 6. Three categories of the CLASS report on the self-

Table 15. Summary of TOLT for Teaching Methods (n=69)

Group	Pre Score (%)	Post Score (%)	Avg Growth (%)
GpA	40.40	40.43	0.086
TEL	55.91	58.57	4.762
POGIL	59.55	69.50	16.718

perceived problem-solving skills of the participants in each teaching methodology. All of the teaching methodologies reported expert like shifts in the problem-solving categories with the exception of GpA. The GpA methodology reported a neutral shift in one category, problem-solving general. This correlates with the TOLT scores in that the GpA reported a menial improvement in participant problem-solving skills while the TEL and POGIL both reported higher improvements. However, the TOLT performances were highly correlated with the pre-assessment scores as reported by the ANCOVA. According to the ANCOVA results of the TOLT, the pre-assessments scores were equally relevant predictors in student problem solving skills as the TOLT with there being a significant difference in the pre-TOLT performance $F(2,57)=315.8$, p=<2e-16 compared to the post-

TOLT performance $F(2,54)=1.886$, $p=0.161$. The results of the TEL and POGIL are comparable to that of literature in that the POGIL teaching methodology has reported to improve student problem-solving skills through group work and guided-inquiry frameworks. However, the GpA methodology, a modification of POGIL, did not report a large improvement in the student problem-solving skills. Similar to the pre-assessment of the ID-PPA, the significant difference between the GpA and other teaching methodologies can be rooted to the gamification mechanic. As students interacted with the GpA methodology, the gamification mechanic would engage the students and peak their interest, however because some of the mechanics were confusing or not intuitive, participants required more effort in understanding the rules rather than building their conceptual understanding. Measuring the cognitive effects of each teaching methodology connects to the conceptual understanding as well as engagement in the learning process. Analyzing the metacognitive effects of each teaching methodology provided clarity into the confidence of the participants on their conceptual understanding as seen in Table 16.

Table 16. Metacognitive Survey (n=58)

Group	%IKWIK	%IKWIDK	%IDKWIK	%IDKWIDK
GpA	46.73	8.41	30.84	14.02
TEL	52.02	11.11	16.67	20.20
POGIL	52.72	7.07	22.28	17.93

In each teaching methodology, the higher the ID-PPA post-assessment scores the more metacognitively aware the participants were. Metacognitively aware refers to respondents reporting predominately positive codes (IKWIK and IKWIDK) compared to the neutral code (IDKWIK) and negative code (IDKWIDK). Both the TEL and POGIL reported comparable results in the positive codes correlating with the conceptual understanding. Though the GpA had slightly lower frequency of positive metacognitive codes compared to the other teaching methodologies, there were a significantly higher frequency of neutral metacognitive codes. The neutral metacognitive codes come predominately from a lack of confidence in their understanding of the content not from misunderstanding of the content. The GpA participants lack of overall conceptual understanding and developing problem-solving skills compared to the other teaching methodologies resulted in a lack of confidence in being able to discern the accuracy in their understanding of the content. The limitations in confidence and the development of problem-solving skills correlates with the reported results of the NASA TLX survey as reported in Table 17. According the ANCOVA, no statistical difference was found between the teaching groups even when controlled for the pre-assessment data $F(2,54)=0.681$, $p=0.540$.

Table 17. NASA TLX (n=58)

Group	Weighted Rating Lesson I	Weighted Rating Lesson II	Weighted Rating Lesson III	Weighted Average
GpA	59.93	40.23	51.39	50.16
TEL	40.74	44.51	43.67	43.01
POGIL	51.99	51.55	41.46	50.32

Each teaching methodology reported comparable overall results in the cognitive load experienced by the participants. The TEL methodology reported a somewhat high overall cognitive load while the POGIL and GpA methodologies reported high overall cognitive loads. Though the NASA TLX survey does not report an official threshold for cognitive overload a safe presumption can be made that high or very high overall cognitive loads can function as thresholds for the phenomenon described as cognitive overload. Since the NASA TLX does not differentiate between each of the cognitive load types, the factors are reported in Table 18 to better understand what cognitive load types effect participants in each of the teaching groups. Mental, physical and temporal demand a reported as intrinsic load while performance effort and frustration are reported as extraneous load.

Table 18. NASA TLX Factors

Lesson	Factor	GpA	POGIL	TEL

Lesson I	Mental Demand	272.1875	238.5714286	170
	Physical Demand	4.6875	27.85714286	25.71428571
	Temporal Demand	162.1875	126.0714286	106.4285714
	Performance	60.625	101.0714286	88.92857143
	Effort	127.1875	231.4285714	118.5714286
	Frustration	272.1875	55	101.4285714
Lesson II	Mental Demand	187.94118	269.411765	192.368421
	Physical Demand	17.058824	20.5882353	29.2105263
	Temporal Demand	92.058824	122.352941	132.105263
	Performance	67.352941	83.8235294	92.3684211
	Effort	124.11765	205	112.368421
	Frustration	115	72.0588235	91.8421053
Lesson III	Mental Demand	236	194	160
	Physical Demand	33	1	0
	Temporal Demand	182.5	98	93
	Performance	101.5	94	174
	Effort	127	206	136
	Frustration	91.5	29	92
Total	Mental Demand	230.4651	246.9444	179.8684
	Physical Demand	16.16279	20.69444	24.07895
	Temporal Demand	139.186	120.4167	117.5
	Performance	72.7907	91.94444	101.8421
	Effort	125.9302	215.4167	117.7632
	Frustration	168.0233	59.44444	95.39474

The values are highlighted green, yellow and red for the top three averages ranked highest, middle highest and lowest values in each teaching group.

A high source of the TEL participant's cognitive load was a result of the mental demand and a split between effort and temporal demand. Amongst the TEL participants a majority of the cognitive load was a result of the intrinsic load. Most of the participants were familiar with the teaching methodology already so most of the focus in their cognitive processing was based on understanding the content. The average cognitive load for the TEL methodology experienced mild fluctuation from lesson to lesson based on the relative difficulty of the chemistry content covered in that lesson. For the POGIL and GpA participants, however, a majority of the cognitive load was a result of extraneous load. Extraneous load is a result of cognitive processing that does not support the overall learning process. As stated before, though the NASA TLX does not differentiate between load types, the NASA TLX categories can provide a safe presumption of where the load comes from. For the POGIL methodology the extraneous load was a result of students adapting to the new learning environment with the mental demand and effort being the highest source of the load. Most participants in the POGIL methodology reported in the interviews that they had no previous experience with a POGIL or guided inquiry teaching methodology. Because of this, participants had to take time to adjust to their roles and responsibilities in the learning environment. As the participants became more familiar with the teaching methodology, the overall expressed cognitive load decreased, as evidenced in Table 16, from lesson I to lesson III. For the GpA methodology, however, the extraneous load was a result of students adapting to the group-learning and gamification mechanics in the teaching environment with frustration and mental demand being the highest source of load. Participants in the GpA methodology experienced high fluctuation in cognitive load across the three lessons. The reduction in the cognitive load experienced in the GpA methodology has more of a direct connection to the group-learning mechanic, similar to the POGIL methodology, and not the gamification mechanic. Participants in the GpA were engaged in the learning process and learned new concepts in the methodology as reported in Table 12, however, 42% of respondents described the gamification mechanic as difficult to learn and adapt to. Because of this difficulty, students experienced a high extraneous load that distracted from the learning process. This does not mean that the gamification mechanic was detrimental to the learning process, but it does require a longer period of time for participants to adapt to the learning environment compared to more traditional guide inquiry teaching methodologies.

CHAPTER 5: Conclusion

As alternative teaching methodologies to the general lecturing methodology continue to develop, edits and longitudinal validation studies are required. The POGIL and TEL methodologies performed comparable to previously reported results in literature both quantitatively and qualitatively. As participants interacted more with the POGIL methodology their problem-solving skills improved while the cognitive load they experienced decreased overall. Participants of the TEL methodology performed comparable to the other methodologies, however a major shift in positive attitudes towards chemistry as well as positive metacognitive results were also reported. There have been few studies measuring the statistical and empirical results of gamification mechanics in the educational setting. The gamification mechanic of the GpA methodology engaged student interest and helped invite them into the learning environment. However, the mechanic did not provide much assistance in growing student problem-solving skills or positive attitudes towards chemistry concepts. GpA showed a negative effect on student attitudes while also having a neutral effect on student conceptual understanding with no statistical difference between it and the other teaching methodologies in performance. A positive effect on problem solving skills and distribution of cognitive overload were also reported in the study. Students in the GpA were somewhat confident in their metacognitive abilities with participants having low confidence in their understanding of the content as reported in the ID-MS and PISI. If the teaching methodology does not provide space for students to clarify conceptual understanding it may result in the development of misconceptions which can cause confusion and a decrease in their metacognitive awareness. Students in the GpA have a self-perceived clearer understanding by interacting with the content but are not actually changing or improving in their performance.

As with all research the study has its limitations. Four relevant limitations are population diversity, recruitment of students, time, and scope of study. The study population included first and second-year students enrolled in general chemistry at a local mid-sized midwestern university. However, a majority of the sample population reported in the study were white, non-Hispanic and female. The study was also implemented at a single institution rather than at multiple institutions which limited the scope of the study. This lack of diversity amongst the sample population and limited institutional implementation makes the results difficult to accurately compare results in another institutional study. Student recruitment limited the sample size recorded in the study. Less than 50% of recruited students were retained in the study. Though this may be standard retention amongst other DBER literature, it limits the statistical analysis and statistical power used to validate results of the study. Time was also a limitation, however it was a limitation reported by participants of the GpA methodology. Participants found that the three weeks of lesson were not always an adequate enough amount of time to adapt to the teaching methodology. The length of time given to complete the lessons (55 minutes) was also limiting in the self-assessment of the participants. They requested more time be offered for them to both adapt and become familiar with the methodology. Though this would be a necessary change in future implementations of the study, student retention is part of the reason why the lessons were limited to a 3 week implementation. After the second lesson throughout the study, participant engagement would decrease resulting in them failing to complete the final lesson and failing to complete post-assessment surveys. Limiting the lesson implementation to 3 weeks allowed for the maximization or retention to keep the highest possible sample population size.

Future work in the gamification of POGIL would seek to focus on two areas: intra-institutional validity study and assessment of cognitive load on specific teaching mechanics. Effective implementation of a new teaching methodology requires validation of its effectiveness. Validation in this circumstance requires submitting the developed activities to the POGIL Clearinghouse, the peer-reviewed process for validating POGIL activity and courses. Experts in the field of guided inquiry and POGIL are given the activities to implement in their own classrooms. After sufficient editing and reviews activities are made available to the general public for use. Along with the POGIL Clearinghouse, experts in education-implemented gamification as well as experts in chemistry education are needed to implement the activity in their classrooms for validation. With a larger selection of institutions this provides a greater sample size of student data allowing for a higher statistical power in the data set as well as greater amount of diversity amongst the student sample population. Seeking to assess the cognitive load of the mechanism in the GpA methodology comes from the lack of information in current literature on what aspects of guided inquiry teaching methodology benefit student performance and which aspects have a neutral effect on student performance. As reported in the thesis the gamification mechanism of the GpA is providing students with greater engagement but not significantly greater problem solving skills. Providing a reproducibility study with a greater sample size will help to provide context to these results.

In editing the current format of the GpA method more emphasis should be placed on student communication and growth. Though the gamification aspect is most helpful in engaging the participants, communication during the POGIL questions provided the most opportunity for students to clarify preconceptions of the chemistry content. The matching style card game time should be reduced from 5 to 3 minutes. Also, the rules should be amended. Though the current format of the GpA requires participants to compete with each other a new edition would benefit from having participants compete with other groups. This would allow to card game mechanic to function less like it currently does, most comparable to UNO®, and more akin to a group version of Go-Fish/Solitaire, a card mechanic used in previous gamified chemistry education literature.

The GpA could function well for a review or introduction of content but would not be something that would need to be implemented long term without further study. GpA is not detrimental to student academic performance, however it only marginally improve the skills, problem solving and attitudes, necessary to improve student academic performance. This seems consistent with the qualitative results of literature but also provides some insight on possibly why there is such a lack in quantitative results in gamification research. Student self-perception is positive with menial descriptive statistics, but a more in-depth analysis along with inferential statistics reveal a less savory narrative.

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APPENDIX A: IRB CONSENT FORM

South Dakota State University
Information Sheet and Consent form
South Dakota State University
Brookings, SD 57007

Study Title: Effects of Gamified POGIL on student performance

Principal Investigator: Dr. Melody Jewell **Graduate Research Assistant:** Mr. Nathan Turner

This an invitation for you ***as a student in science and chemistry courses*** to participate in a research project under the direction of Dr. Melody Jewell. The project is entitled **Effects of Gamified POGIL on student performance**
Your participation in this research study is voluntary and you may discontinue participation at any time.

The main purpose of this study is to assess the impact of incorporating a gamified version of process oriented guided inquiry learning (POGIL) activities in general chemistry. Two research questions will be addressed: 1) What is the impact of gPa (Gamified POGIL activities) on student a) academic performance, b) conceptual understanding and c) engagement? 2) How do gPa encourage small group interaction & problem-solving skills?

Participation in this project will require 5-7 hours of devoted time divided as follows: one 30 min Introduction Meeting, three 90 min Intervention Meetings, one 30 min Assessment Group Interview.

If you consent to participate, you will be involved in the following process, which will take about 5-7 hours of your time during the semester. Students who consent to participate in the study will be placed in one of three groups, traditional learning, POGIL, and gamified-POGIL. Students participating in this study will be exposed to all three learning strategies. Students in all three groups will be completing: (1) a demographic survey, (2). attend scheduled meetings for the groups. These meetings will be based on student preferred schedule after obtaining student consent for participation. (3). Complete the pre- and post-quizzes and surveys (4). Attend the final group interview and individual interviews as needed.

For students participating in the study, they will need to consent to having their responses on quizzes, and surveys be utilized for research purposes for each of the three learning strategies. If students do not give their consent to participate, they can still attend these sessions, but need not complete interviews or surveys related to the project. Student attendance for these sessions is not required for students who do not consent. Data from non-consenting students will not be used for this project or any part of the study.

There are no risks for participating in this study. There are no benefits for participating in this study. Being an educational research project, it is very likely that students may experience gains in their subject matter knowledge. To ensure consistency the groups are likely to be switched so that students get experience in each of the three approaches of learning.

Paper data used in this study will be collected and locked in a filing cabinet in a secure room that will only be accessed by the principal investigator and the graduate researcher approved by the IRB. Electronic data used in this study will be collected and stored on a password protected hard drive locked in a secure room that will only be accessed by the principal investigator and researcher approved by the IRB. Students who participate in the study will be audibly recorded and coded. Students will be given pseudonyms to make their identity anonymous. Your responses for surveys, interviews and assessments are strictly confidential. The data will be available only to the PI and the graduate researcher. When the data and analysis are presented, you will not be linked to the data by your name, title or any other identification.

If you have any questions regarding this study, you may contact the Project Director. If you have questions regarding your rights as a participant, you can contact the SDSU Research Compliance Coordinator at (605) 688-6975 or SDSU.IRB@sdstate.edu.

You must be 18 or older to participate.

I have read the above and have had any questions answered.

Name of participant____________________Signature_______________________ Date_______
SDSU IRB approved IRB-2102007-EXM

APPENDIX B: GAME LESSONS

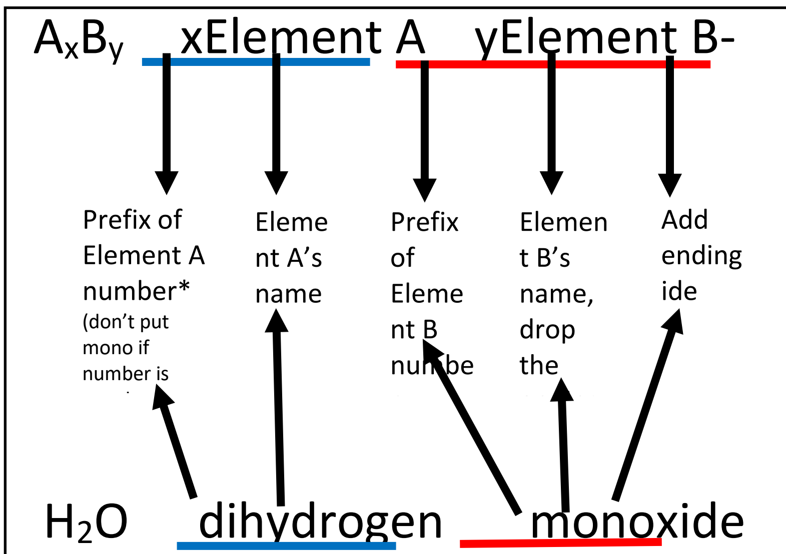
Because of the size of the files three sections of the completed appendix can be accessed at the site https://gpacourseactivities.wixsite.com/appendix. Complete information is under the tab ***Gamification POGIL Activities***. The tab is password protected. The password to access the tab is GpA2022Access. Below is an example of the first gamification POGIL activity.

G-POGIL Activity Lesson I

Formula Writing, Covalent Naming & Ionic Naming

Compound type	Structure	Example
Monoatomic ions	$A^{y+}\ B^{x-} \rightarrow A_xB_y$	$Ca^{2+}\ F^- \rightarrow Ca^{2+}F^- \rightarrow CaF_2$
Polyatomic ions	$A^{y+}\ (BC_z)^{x-} \rightarrow A_x(BC_z)_y$	$Ca^{2+}\ NO_3^- \rightarrow Ca^{2+}NO_3^- \rightarrow Ca(NO_3)_2$

Cu and Cl Copper and Chlor**ine**	Cu and Cl Copper and Chlor**ine**	Ca and F Calcium and Fluor**ine**	Ca and NO_3 Calcium and Nitr**ate**
$Cu^{2+}\ Cl^-$ $CuCl_2$ Copper (II) Chlor<u>ide</u>	$Cu^+\ Cl^-$ CuCl Copper (I) Chlor<u>ide</u>	$Ca^{2+}\ F^-$ CaF_2 Calcium Fluor<u>ide</u>	$Ca^{2+}\ NO_3^-$ $Ca(NO_3)_2$ Calcium Nitr<u>ate</u>



Number	Prefix
1	mono-
2	di-
3	tri-
4	tetra-
5	penta-
6	hexa-
7	hepta-
8	octa-
9	nona-
10	deca-

Activity

1. Identify Common Trends based on matches in cards

2. What are questions or disagreements amongst your group?

Exercises

1. How do we name (binary) covalent compounds?

2. What is the formula for Magnesium Chloride?

3. What are the three suffixes that a compound can take on in chemical naming?

4. How would you name $CuBr_2$?

Critical Thinking

1. In the name of an ionic compound, which ion is always written first- the anion or the cation? Which ion has the last name changed?

2. MgF_2. What is the name of this compound? What is the charge on the magnesium ion? What is the charge on each fluoride ion?

3. What are different types of multiple bond? How many valence electrons are shared in each type of multiple bonds?

4. How are transition metals named in an ionic compound?

5. Develop a flow-chart or system for naming both ionic and covalent compounds.

6. Determine the formula of Chromium (III) Hydroxide

7. Determine the formula of Calcium Carbonate

8. Determine the formula of Gallium Bromide

APPENDIX C: POGIL LESSONS

Because of the size of the files three sections of the completed appendix can be accessed at the site https://gpacourseactivities.wixsite.com/appendix. Complete information is under the tab ***POGIL Activities***. The tab is password protected. The password to access the tab is POGIL2022Access. Items can also be requested by emailing nathan.turner@sdstate.edu or nathanturner01@gmail.com with the subject line "ATTN:POGIL Lessons"

APPENDIX D: GAME ELEMENTS

Because of the size of the files three sections of the completed appendix can be accessed at the site https://gpacourseactivities.wixsite.com/appendix. Complete information is under the tab ***Gamification POGIL Activities***. The tab is password protected. The password to access the tab is GpA2022Access.

APPENDIX E: INSTRUCTOR DESIGNED METACOGNITIVE SURVEY

Lesson I Post-Assessment

1. In the name of an ionic compound, which ion is written first- the anion or the cation?
    a. Anion
    b. Cation

How confident are you in your response?				
1 Not Confident	2 Slightly Confident	3 Somewhat Confident	4 Fairly Confident	5 Completely Confident

2. Determine the formula of Chromium (III) Hydroxide?
    a. $Cr(OH)_3$
    b. $Cr(OH)_2$
    c. $Co(OH)_3$
    d. $Co(OH)_2$

How confident are you in your response?				
1 Not Confident	2 Slightly Confident	3 Somewhat Confident	4 Fairly Confident	5 Completely Confident

3. MgF_2. What is the name of this compound?
    a. Magnesium (II) Fluoride
    b. Magnesium Difluoride
    c. Magnesium Fluoride
    d. None of the above

How confident are you in your response?				
1 Not Confident	2 Slightly Confident	3 Somewhat Confident	4 Fairly Confident	5 Completely Confident

4. Determine the formula of Calcium Carbonate?
    a. $Ca(CO_3)_2$
    b. $CaCO_3$
    c. Ca_2CO_3
    d. None of the above

How confident are you in your response?				
1 Not Confident	2 Slightly Confident	3 Somewhat Confident	4 Fairly Confident	5 Completely Confident

5. Determine the formula of Gallium Bromide?
    a. GaBr
    b. Ga_3Br_3
    c. Ga_3Br
    d. None of the above

How confident are you in your response?				
1 Not Confident	2 Slightly Confident	3 Somewhat Confident	4 Fairly Confident	5 Completely Confident

Lesson II Post-Assessment

1. What direction does a dipole travel?
    a. Toward the more electronegative species
    b. Toward the less electronegative species
    c. Equal distribution
    d. Shared distribution

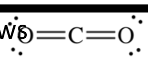
How confident are you in your response?

1	2	3	4	5
Not Confident	Slightly Confident	Somewhat Confident	Fairly Confident	Completely Confident

2. Can you have polar bonds within a non-polar molecule?
    a. No, a polar bond would make the compound polar
    b. No, a polar bond can't exist within a non-polar bond
    c. Yes, if a compound is large enough in size or has a large enough molecular mass
    d. Yes, a polar bond must exist in a non-polar compound

How confident are you in your response?

1	2	3	4	5
Not Confident	Slightly Confident	Somewhat Confident	Fairly Confident	Completely Confident

3. The CO_2 Lewis structure is as follows  . What is electronegativity difference between C and O?
    a. 0.9
    b. -0.9
    c. None of the above

How confident are you in your response?

1	2	3	4	5
Not Confident	Slightly Confident	Somewhat Confident	Fairly Confident	Completely Confident

4. Based on the dipole(s) of CCl_4. Is the compound Polar or Nonpolar?
    a. Polar because the atoms bonded to the central atom are the same
    b. Polar because the atoms bonded to the central atom have a higher electronegativity and are symmetrical
    c. Nonpolar because the atoms bonded to the central atom are the same
    d. Nonpolar because the atoms bonded to the central atom have a higher electronegativity and are symmetrical

How confident are you in your response?

1	2	3	4	5
Not Confident	Slightly Confident	Somewhat Confident	Fairly Confident	Completely Confident

5. What is the electronegativity difference of LiF? What is the bond (intramolecular force)?
    a. 3.0 Covalent
    b. -3.0 Covalent
    c. 3.0 Ionic
    d. None of the above

How confident are you in your response?

1	2	3	4	5
Not Confident	Slightly Confident	Somewhat Confident	Fairly Confident	Completely Confident

Lesson III Post-Assessment

1. $4Fe_{(s)}$ +3 $O_{2\ (g)}$ → $4Fe_2O_{3\ (s)}$ Indicate which element is reduced and which is oxidized
   a. Fe oxidized, O reduced
   b. Fe reduced, O oxidized
   c. Fe reduced, O reduced
   d. Fe oxidized, O oxidized

How confident are you in your response?				
1 Not Confident	2 Slightly Confident	3 Somewhat Confident	4 Fairly Confident	5 Completely Confident

2. $CH_{4\ (g)}$ + 2 $O_{2\ (g)}$ → $CO_{2\ (g)}$ + 2 $H_2O_{\ (l)}$ which atom is oxidized and which atom is reduced?
   a. C reduced, O oxidized
   b. C oxidized, O oxidized
   c. C oxidized, O reduced
   d. None of the above

How confident are you in your response?				
1 Not Confident	2 Slightly Confident	3 Somewhat Confident	4 Fairly Confident	5 Completely Confident

3. Complete the double displacement reaction $2HNO_{3\ (aq)}$ + $Mg(OH)_{2(aq)}$ →
   a. $Mg(NO_3)_{2\ (aq)}$ + $2H_2O_{(aq)}$
   b. $MgNO_{3\ (aq)}$ + $H_2O_{(aq)}$
   c. $Mg(NO_3)_{2\ (aq)}$ + $2HO_{(aq)}$
   d. $2Mg(NO_3)_{2\ (aq)}$ + $H_2O_{(aq)}$

How confident are you in your response?				
1 Not Confident	2 Slightly Confident	3 Somewhat Confident	4 Fairly Confident	5 Completely Confident

4. Complete the double displacement reaction $2LiCl_{\ (aq)}$ + $Na_2CO_{3\ (aq)}$ →
   a. $LiCO_{3\ (aq)}$ + $2NaCl_{\ (aq)}$
   b. $Li(CO_3)_{2\ (aq)}$ + $NaCl_{\ (aq)}$
   c. $Li_2CO_{3\ (aq)}$ + $Na_2Cl_{\ (aq)}$
   d. $Li_2CO_{3\ (aq)}$ + $2NaCl_{\ (aq)}$

How confident are you in your response?				
1 Not Confident	2 Slightly Confident	3 Somewhat Confident	4 Fairly Confident	5 Completely Confident

5. Based on $Cu_{\ (s)}$ + $2AgNO_{3\ (aq)}$ ←→ 2 $Ag_{\ (s)}$ + $Cu(NO_3)_{2\ (aq)}$ indicate oxidation number for Ag.
   a. Reactant: Ag^+, Product: Ag^0
   b. Reactant: Ag^{3+}, Product: Ag^0
   c. Reactant: Ag^0, Product: Ag^{3+}
   d. Reactant: Ag^0, Product: Ag^+

How confident are you in your response?				
1 Not Confident	2 Slightly Confident	3 Somewhat Confident	4 Fairly Confident	5 Completely Confident

Lesson IV Post-Assessment

1. How many grams of Gold are in 0.500 moles of Au?
    a. 98.48g
    b. 0.500g
    c. 0.00253g
    d. None of the above

How confident are you in your response?				
1 Not Confident	2 Slightly Confident	3 Somewhat Confident	4 Fairly Confident	5 Completely Confident

2. Determine the molar mass of CO_2?
    a. 32.00
    b. 28.01
    c. 44.01
    d. None of the above

How confident are you in your response?				
1 Not Confident	2 Slightly Confident	3 Somewhat Confident	4 Fairly Confident	5 Completely Confident

3. $2\ C_4H_{10\ (l)} + 13\ O_{2\ (g)} \rightarrow 8\ CO_{2\ (g)} + 10\ H_2O_{\ (g)}$ how many moles of water are produced if 5.7 moles of oxygen gas react?
    a. 5.7 mol
    b. 4.38 mol
    c. 18.7 mol
    d. None of the above

How confident are you in your response?				
1 Not Confident	2 Slightly Confident	3 Somewhat Confident	4 Fairly Confident	5 Completely Confident

4. It is the following statement true or false? Explain. “There are more carbon atoms in 48 grams of CO_2 than in 12 grams of elemental carbon”.
    a. True
    b. False

How confident are you in your response?				
1 Not Confident	2 Slightly Confident	3 Somewhat Confident	4 Fairly Confident	5 Completely Confident

5. To convert between grams and moles of the same element, what conversion factor(s) do we use?
    a. Molar Ratio
    b. Molar Mass
    c. Avagdro’s Number
    d. None of the above

How confident are you in your response?				
1 Not Confident	2 Slightly Confident	3 Somewhat Confident	4 Fairly Confident	5 Completely Confident

Lesson V Post-Assessment

1. CH_2O is the compound formaldehyde, what intermolecular forces are present in this compound?

   I. London Dispersion Forces   II. Hydrogen Bonding   III. Dipole-Dipole

   a. I only
   b. I and II
   c. I and III
   d. III only

How confident are you in your response?				
1 Not Confident	2 Slightly Confident	3 Somewhat Confident	4 Fairly Confident	5 Completely Confident

2. Can you have polar bonds within a non-polar molecule?
   a. No, a polar bond would make the compound polar
   b. No, a polar bond can't exist within a non-polar bond
   c. Yes, if a compound is large enough in size or has a large enough molecular mass
   d. Yes, a polar bond must exist in a non-polar compound

How confident are you in your response?				
1 Not Confident	2 Slightly Confident	3 Somewhat Confident	4 Fairly Confident	5 Completely Confident

3. NO has a boiling point of -150°C and N_2 has a boiling point of -392°C. Which has a stronger IMF?
   a. NO because it has less N than N_2
   b. NO because it has a higher boiling point than N_2
   c. N_2 because it has more N than NO
   d. N_2 because it has a lower boiling point than NO

How confident are you in your response?				
1 Not Confident	2 Slightly Confident	3 Somewhat Confident	4 Fairly Confident	5 Completely Confident

4. Which compound has a stronger hydrogen bond $CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2OH$ vs CH_3CH_2OH?
   a. $CH_3CH_2CH_2CH_2CH_2CH_2CH_2OH$ has stronger hydrogen bonding
   b. CH_3CH_2OH has stronger hydrogen bonding

How confident are you in your response?				
1 Not Confident	2 Slightly Confident	3 Somewhat Confident	4 Fairly Confident	5 Completely Confident

5. Would you expect Hexane $CH_3CH_2CH_2CH_2CH_2CH_3$ to be soluble in Water H_2O?
   a. Yes, because both compounds contain H
   b. Yes, because both compounds have London Dispersion Forces
   c. No, because Hexane is Nonpolar and Water is Polar
   d. No, because Hexane is Polar and Water is Nonpolar

How confident are you in your response?				
1 Not Confident	2 Slightly Confident	3 Somewhat Confident	4 Fairly Confident	5 Completely Confident

APPENDIX F: DEMOGRAPHIC SURVEY

Name:

Institution/College:

Year in College (based on credits):

Undergraduate: 1st Year 2nd Year 3rd Year 4th Year 5th+ Year

Graduate: 1st Year 2nd Year 3rd Year 4th Year 5th+ Year

Recent Graduate: <1 Year 1-2 Years 3+ Year

Major:

Sex:

Race:

White (Non-Hispanic or Latino)

Black/African American

American Indian/Alaska Native

Asian

Native Hawaiian and other Pacific Islander

Hispanic or Latino

GPA:

High school GPA

Most Recent GPA:

[] Check box if Most recent GPA is your high school GPA

Test Scores:

ACT:

[] Check If did not take exam

SAT:

[] Check if did not take exam

GRE:

[] Check if did not take exam

APPENDIX G: INSTRUCTOR DESIGNED PRE-ASSESSMENT QUIZZES
Lesson 1-3

Name:____ Date:_______________

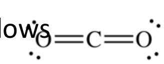
Research ID:______________________________

Each questions is worth 2 points

1. Determine the formula of Calcium Carbonate?
    a. $Ca(CO_3)_2$
    b. $CaCO_3$
    c. Ca_2CO_3
    d. None of the above
2. Can you have polar bonds within a non-polar molecule?
    a. No, a polar bond would make the compound polar
    b. No, a polar bond can't exist within a non-polar bond
    c. Yes, if a compound is large enough in size or has a large enough molecular mass
    d. Yes, a polar bond must exist in a non-polar compound
3. Determine the formula of Gallium Bromide?
    a. GaBr
    b. Ga_3Br_3
    c. Ga_3Br
    d. None of the above
4. What direction does a dipole travel?
    a. Toward the more electronegative species
    b. Toward the less electronegative species
    c. Equal distribution
    d. Shared distribution
5. MgF_2. What is the name of this compound?
    a. Magnesium (II) Fluoride
    b. Magnesium Difluoride
    c. Magnesium Fluoride
    d. None of the above
6. $CH_{4\,(g)} + 2\ O_{2\,(g)} \rightarrow CO_{2\,(g)} + 2\ H_2O_{\,(l)}$ which atom is oxidized and which atom is reduced?
    a. C reduced, O oxidized
    b. C oxidized, O oxidized
    c. C oxidized, O reduced
    d. None of the above
7. $4Fe_{\,(s)} + 3\ O_{2\,(g)} \rightarrow 4Fe_2O_{3\,(s)}$ Indicate which element is reduced and which is oxidized
    a. Fe oxidized, O reduced
    b. Fe reduced, O oxidized
    c. Fe reduced, O reduced
    d. Fe oxidized, O oxidized
8. Determine the formula of Chromium (III) Hydroxide?
    a. $Cr(OH)_3$
    b. $Cr(OH)_2$

   c. $Co(OH)_3$
   d. $Co(OH)_2$

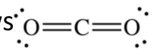
9. Complete the double displacement reaction $2LiCl_{(aq)} + Na_2CO_{3\,(aq)} \rightarrow$
   a. $LiCO_{3\,(aq)} + 2NaCl_{(aq)}$
   b. $Li(CO_3)_{2\,(aq)} + NaCl_{(aq)}$
   c. $Li_2CO_{3\,(aq)} + Na_2Cl_{(aq)}$
   d. $Li_2CO_{3\,(aq)} + 2NaCl_{(aq)}$
10. In the name of an ionic compound, which ion is written first- the anion or the cation?
    a. Anion
    b. Cation
11. What is the electronegativity difference of LiF? What is the bond (intramolecular force)?
    a. 3.0 Covalent
    b. -3.0 Covalent
    c. 3.0 Ionic
    d. None of the above
12. Based on $Cu_{(s)} + 2AgNO_{3\,(aq)} \leftarrow\rightarrow 2\,Ag_{(s)} + Cu(NO_3)_{2\,(aq)}$ indicate oxidation number for Ag.
    a. Reactant: Ag^{+}, Product: Ag^{0}
    b. Reactant: Ag^{3+}, Product: Ag^{0}
    c. Reactant: Ag^{0}, Product: Ag^{3+}
    d. Reactant: Ag^{0}, Product: Ag^{+}

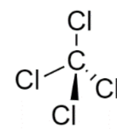
13. Based on the dipole(s) of CCl_4. Is the compound Polar or Nonpolar?
    a. Polar because the atoms bonded to the central atom are the same
    b. Polar because the atoms bonded to the central atom have a higher electronegativity and are symmetrical
    c. Nonpolar because the atoms bonded to the central atom are the same
    d. Nonpolar because the atoms bonded to the central atom have a higher electronegativity and are symmetrical
14. Complete the double displacement reaction $2HNO_{3\,(aq)} + Mg(OH)_{2(aq)} \rightarrow$
    a. $Mg(NO_3)_{2\,(aq)} + 2H_2O_{(aq)}$
    b. $MgNO_{3\,(aq)} + H_2O_{(aq)}$
    c. $Mg(NO_3)_{2\,(aq)} + 2HO_{(aq)}$
    d. $2Mg(NO_3)_{2\,(aq)} + H_2O_{(aq)}$
15. The CO_2 Lewis structure is as follows  . What is electronegativity difference between C and O?
    a. 0.9
    b. -0.9
    c. None of the above

Lessons 4-5

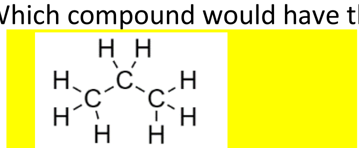
Name:____ Date:_______________

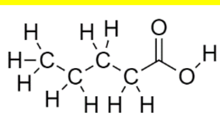
Research ID:_____________________________

1. The CO_2 Lewis structure is as follows  . What is electronegativity difference between C and O?
    a. 0.9
    b. -0.9
    c. None of the above
2. What is the strongest intermolecular present inf the following structure



    a. Hydrogen Bonding
    b. Dipole Dipole
    c. Lodon Dispersion Forces
    d. Ionic Bond
3. NO has a boiling point of -150°C and N_2 has a boiling point of -392°C. Which has a stronger IMF?
    a. NO because it has less N than N_2
    b. NO because it has a higher boiling point than N_2
    c. N_2 because it has more N than NO
    d. N_2 because it has a lower boiling point than NO
4. CH_2O is the compound formaldehyde, what intermolecular forces are present in this compound?
5. I. London Dispersion Forces   II. Hydrogen Bonding   III. Dipole-Dipole
    a. I only
    b. I and II
    c. I and III
    d. III only
6. Can you have polar bonds within a non-polar molecule?
    a. No, a polar bond would make the compound polar
    b. No, a polar bond can't exist within a non-polar bond
    c. Yes, if a compound is large enough in size or has a large enough molecular mass
    d. Yes, a polar bond must exist in a non-polar compound
7. Would you expect Hexane $CH_3CH_2CH_2CH_2CH_2CH_3$ to be soluble in Water H_2O?
    a. Yes, because both compounds contain H
    b. Yes, because both compounds have London Dispersion Forces
    c. No, because Hexane is Nonpolar and Water is Polar
    d. No, because Hexane is Polar and Water is Nonpolar
8. Which compound would have the highest vapor pressure?



b 

9. Order the inter molecular forces in order of strongest to weakest: 1)London Dispersion Forces, 2)Hydrogen Bonding, 3)Dipole-Dipole
    a. 1>2>3
    b. 3>2>1
    c. 2>3>1
    d. 1>3>2

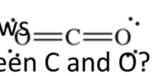
10. How many molecules are in 1 mole of Na
    a. 22.990 molecules
    b. 1 molecule
    c. 6.022×10^{23} molecules
    d. None of the above
11. Which of the following is Avogadro's number
    a. 6.022×10^{23}
    b. 6.022×10^{-23}
    c. -1
    d. 1
12. What is the molar mass of KCl
    a. 119.00
    b. 113.64
    c. 110.01
    d. 74.55
13. How many grams of H_2 are in 0.500 moles of H_2
    a. 1
    b. 0.5
    c. 2
    d. 0
14. There are more molecules in 1 mole of Magnesium than 1 mole of Phosphorus
    a. True
    b. False
15. There are more carbon atoms in 48 grams of CO_2 than in 12 grams of elemental carbon
    a. True
    b. False
16. 1 mole of Lithium has a lesser mass than 1 mole of Aluminum
    a. True
    b. False

APPENDIX H: INSTRUCTOR DESIGNED POST-ASSESSMENT QUIZZES

Lessons 1-3

Name:____ Date:______________________

Research ID:_____________________________

1. What is the electronegativity difference of LiF? What is the bond (intramolecular force)?
    a. 3.0 Covalent
    b. -3.0 Covalent
    c. 3.0 Ionic
    d. None of the above
2. Determine the formula of Gallium Bromide?
    a. GaBr
    b. Ga_3Br_3
    c. Ga_3Br
    d. None of the above
3. MgF_2. What is the name of this compound?
    a. Magnesium (II) Fluoride
    b. Magnesium Difluoride
    c. Magnesium Fluoride
    d. None of the above
4. Can you have polar bonds within a non-polar molecule?
    a. No, a polar bond would make the compound polar
    b. No, a polar bond can't exist within a non-polar bond
    c. Yes, if a compound is large enough in size or has a large enough molecular mass
    d. Yes, a polar bond must exist in a non-polar compound
5. Determine the formula of Chromium (III) Hydroxide?
    a. $Cr(OH)_3$
    b. $Cr(OH)_2$
    c. $Co(OH)_3$
    d. $Co(OH)_2$
6. The CO_2 Lewis structure is as follows  . What is electronegativity difference between C and O?
    a. 0.9
    b. -0.9
    c. None of the above
7. Complete the double displacement reaction $2HNO_{3\,(aq)} + Mg(OH)_{2(aq)} \rightarrow$
    a. $Mg(NO_3)_{2\,(aq)} + 2H_2O_{(aq)}$
    b. $MgNO_{3\,(aq)} + H_2O_{(aq)}$
    c. $Mg(NO_3)_{2\,(aq)} + 2HO_{(aq)}$
    d. $2Mg(NO_3)_{2\,(aq)} + H_2O_{(aq)}$
8. In the name of an ionic compound, which ion is written first- the anion or the cation?
    a. Anion
    b. Cation
9. Determine the formula of Calcium Carbonate?

a. $Ca(CO_3)_2$
b. $CaCO_3$
c. Ca_2CO_3
d. None of the above

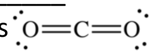
10. Complete the double displacement reaction $2LiCl_{(aq)} + Na_2CO_{3\,(aq)} \rightarrow$
    a. $LiCO_{3\,(aq)} + 2NaCl_{(aq)}$
    b. $Li(CO_3)_{2\,(aq)} + NaCl_{(aq)}$
    c. $Li_2CO_{3\,(aq)} + Na_2Cl_{(aq)}$
    d. $Li_2CO_{3\,(aq)} + 2NaCl_{(aq)}$
11. $CH_{4\,(g)} + 2\,O_{2\,(g)} \rightarrow CO_{2\,(g)} + 2\,H_2O_{(l)}$ which atom is oxidized and which atom is reduced?
    a. C reduced, O oxidized
    b. C oxidized, O oxidized
    c. C oxidized, O reduced
    d. None of the above
12. Based on $Cu_{(s)} + 2AgNO_{3\,(aq)} \leftrightarrow 2\,Ag_{(s)} + Cu(NO_3)_{2\,(aq)}$ indicate oxidation number for Ag.
    a. Reactant: Ag^+, Product: Ag^0
    b. Reactant: Ag^{3+}, Product: Ag^0
    c. Reactant: Ag^0, Product: Ag^{3+}
    d. Reactant: Ag^0, Product: Ag^+

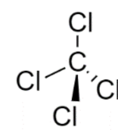
13. What direction does a dipole travel?
    a. Toward the more electronegative species
    b. Toward the less electronegative species
    c. Equal distribution
    d. Shared distribution
14. Based on the dipole(s) of CCl_4. Is the compound Polar or Nonpolar?
    a. Polar because the atoms bonded to the central atom are the same
    b. Polar because the atoms bonded to the central atom have a higher electronegativity and are symmetrical
    c. Nonpolar because the atoms bonded to the central atom are the same
    d. Nonpolar because the atoms bonded to the central atom have a higher electronegativity and are symmetrical
15. $4Fe_{(s)} + 3\,O_{2\,(g)} \rightarrow 4Fe_2O_{3\,(s)}$ Indicate which element is reduced and which is oxidized
    a. Fe oxidized, O reduced
    b. Fe reduced, O oxidized
    c. Fe reduced, O reduced
    d. Fe oxidized, O oxidized

Lessons 4-5

Name:_______________________________________ Date:________________________

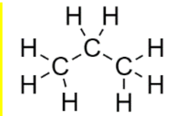
Research ID:________________________________

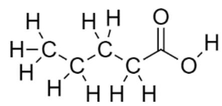
1. The CO_2 Lewis structure is as follows  . What is electronegativity difference between C and O?
    a. 0.9
    b. -0.9
    c. None of the above
2. How many molecules are in 1 mole of Na
    a. 22.990 molecules
    b. 1 molecule
    c. 6.022×10^{23} molecules
    d. None of the above
3. What is the strongest intermolecular present inf the following structure



    a. Hydrogen Bonding
    b. Dipole Dipole
    c. Lodon Dispersion Forces
    d. Ionic Bond
4. How many grams of H_2 are in 0.500 moles of H_2
    a. 1
    b. 0.5
    c. 2
    d. 0
5. NO has a boiling point of -150°C and N_2 has a boiling point of -392°C. Which has a stronger IMF?
    a. NO because it has less N than N_2
    b. NO because it has a higher boiling point than N_2
    c. N_2 because it has more N than NO
    d. N_2 because it has a lower boiling point than NO
6. Which of the following is Avogadro's number
    a. 6.022×10^{23}
    b. 6.022×10^{-23}
    c. -1
    d. 1
7. CH_2O is the compound formaldehyde, what intermolecular forces are present in this compound?
    I. London Dispersion Forces II. Hydrogen Bonding III. Dipole-Dipole
    a. I only
    b. I and II
    c. I and III
    d. III only
8. What is the molar mass of KCl
    a. 119.00
    b. 113.64
    c. 110.01
    d. 74.55
9. Can you have polar bonds within a non-polar molecule?
    a. No, a polar bond would make the compound polar
    b. No, a polar bond can't exist within a non-polar bond
    c. Yes, if a compound is large enough in size or has a large enough molecular mass

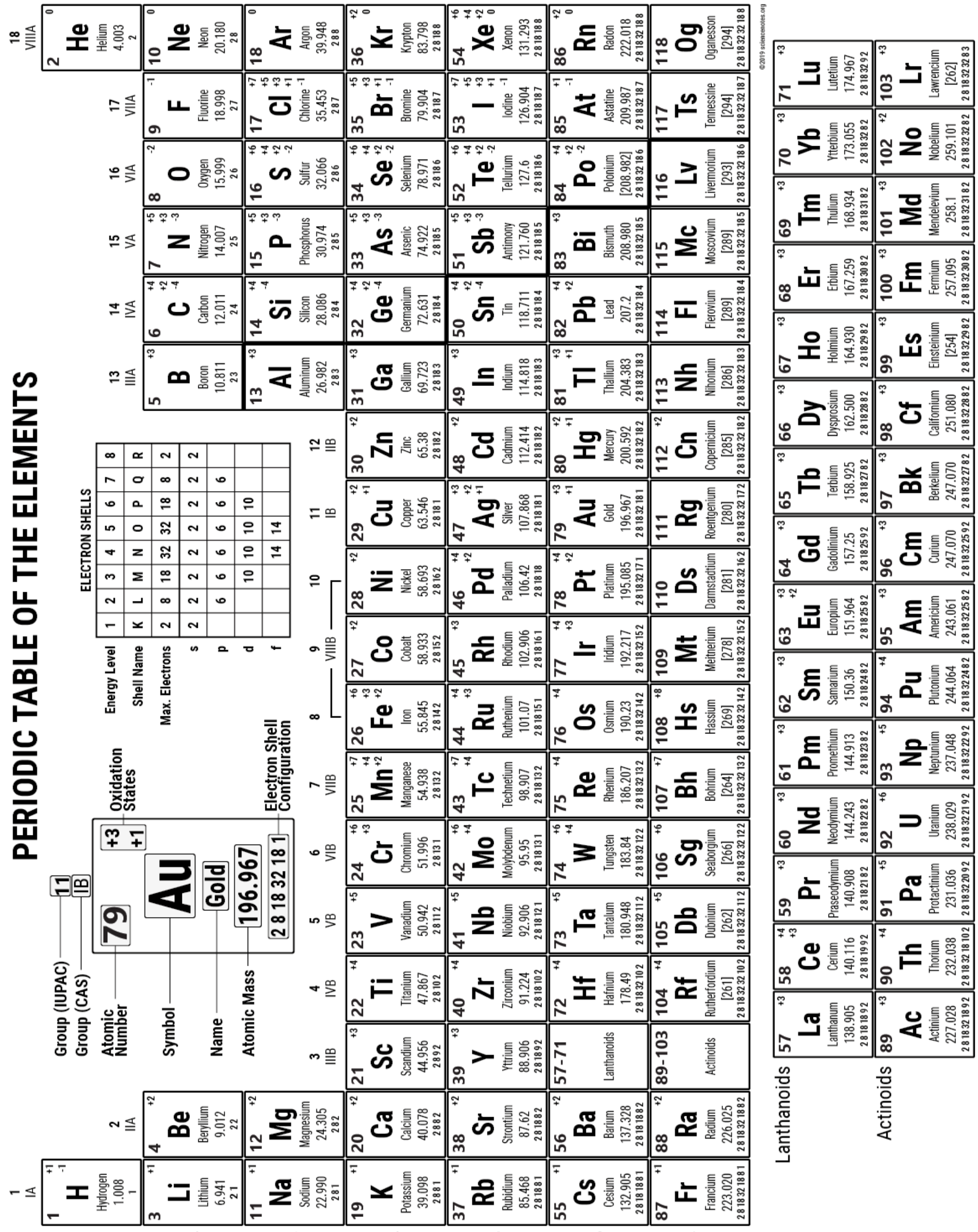
   d. Yes, a polar bond must exist in a non-polar compound

10. Would you expect Hexane $CH_3CH_2CH_2CH_2CH_2CH_3$ to be soluble in Water H_2O?
    a. Yes, because both compounds contain H
    b. Yes, because both compounds have London Dispersion Forces
    c. No, because Hexane is Nonpolar and Water is Polar
    d. No, because Hexane is Polar and Water is Nonpolar
11. Which compound would have the highest vapor pressure?
    a. 

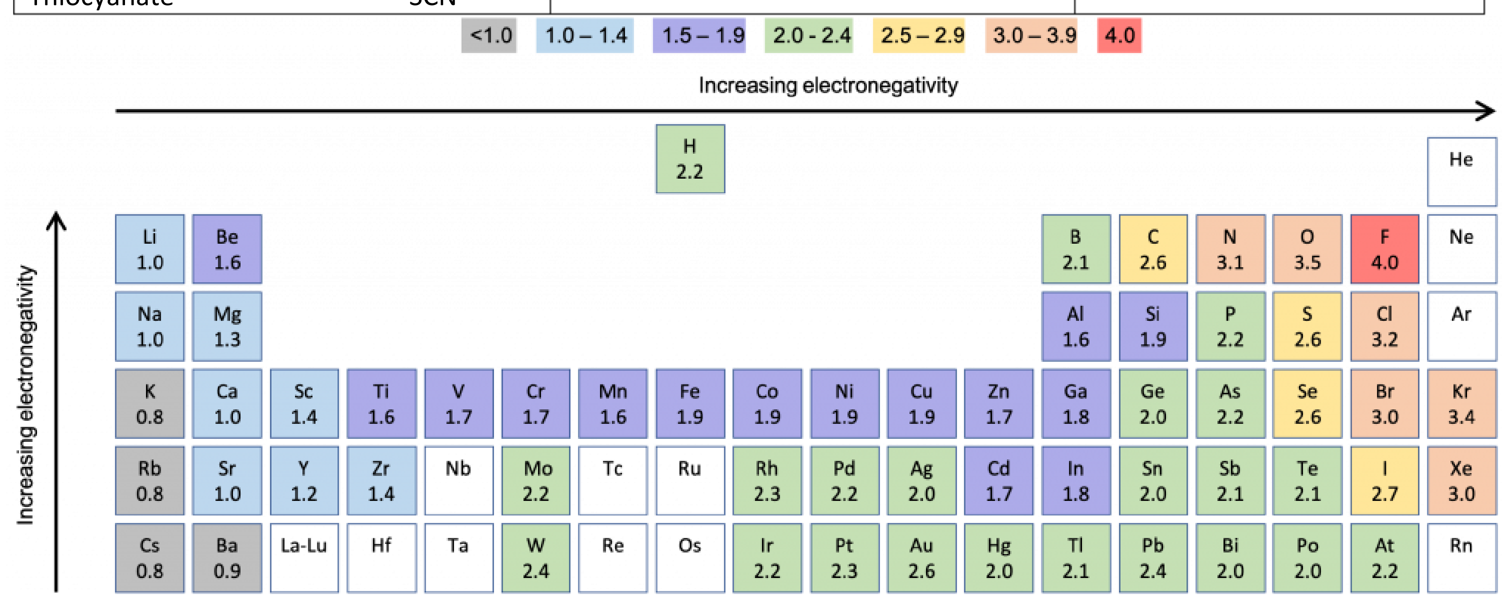
    b 

12. Order the inter molecular forces in order of strongest to weakest: 1)London Dispersion Forces, 2)Hydrogen Bonding, 3)Dipole-Dipole
    a. 1>2>3
    b. 3>2>1
    c. 2>3>1
    d. 1>3>2
13. There are more carbon atoms in 48 grams of CO_2 than in 12 grams of elemental carbon
    a. True
    b. False
14. 1 mole of Lithium has a lesser mass than 1 mole of Aluminum
    a. True
    b. False
15. There are more molecules in 1 mole of Magnesium than 1 mole of Phosphorus
    a. True
    b. False

APPENDIX I: PERIODIC TABLE



Positive Ions					
1+ ions					
Ammonium NH_4^+					
Hydronium H_3O^+					
Negative Ions					
1- ions		**2- ions**		**3-ions**	
Acetate	$C_2H_3O_2^-$	Carbonate	CO_3^{2-}	Phosphate	PO_4^{3-}
Chlorate	ClO_3^-	Chromate	CrO_4^{2-}		
Chlorite	ClO_2^-	Dichromate	$Cr_2O_7^{2-}$		
Cyanide	CN^-	Hydrogen Phosphate	HPO_4^{2-}		
Dihydrogen Phosphate	$H_2PO_4^-$	Peroxide	O_2^{2-}		
Bicarbonate HCO3-	HCO_3^-	Sulfate	SO_4^{2-}		
Bisulfate	HSO_4^-	Sulfite	SO_3^{2-}		
Hydroxide	OH^-	Thiosulfate	$S_2O_3^{2-}$		
Hypochlorite	ClO^-				
Nitrate	NO_3^-				
Nitrite	NO_2^-				
Perchlorate	ClO_4^-				
Permanganate	MnO_4^-				
Thiocyanate	SCN^-				



APPENDIX J: TEST OF LOGICAL THINKING

Test of Logical Thinking (TOLT) Instrument

(TOLT) which was developed by Tobin and Capie (1981). The test consists of ten items measuring five reasoning modes including: proportional reasoning (items 1 & 2), controlling variables (items 3 & 4), probabilistic reasoning (items 5 & 6), correlational reasoning (items 7 & 8), and combinatorial reasoning (items 9 & 10). The items 1 to 8, consist of two parts of responding and reasoning, and to get a score of 1, students need to respond to both parts correctly. In addition, to get a score of 1 for items 9 and 10, students need to list all the possible combinations

Orange Juice #1

1. Four large oranges are squeezed to make six glasses of juice. How much juice can be made from six oranges?

a) 7 glasses b) 8 glasses c) 9 glasses d) 10 glasses e) other

2. What was the reason for your answer to question 1?

a) The number of glasses compared to the number of oranges will always be in the ratio 3 to 2.
b) With more oranges, the difference will be less.
c) The difference in the numbers will always be two.
d) With four oranges the difference was 2. With six oranges the difference would be two more.
e) There is no way of predicting.

Orange Juice #2

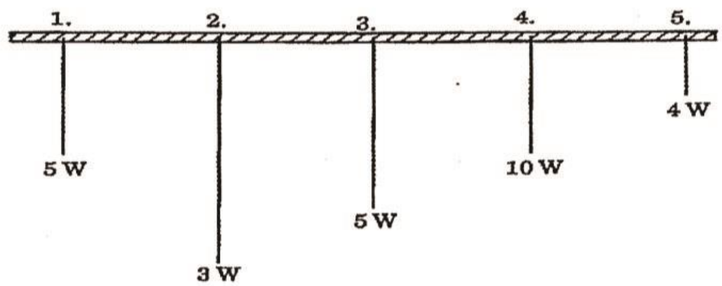
3. How many oranges are needed to make 13 glasses of juice?

a) 6 1/2 oranges b) 8 2/3 oranges c) 9 oranges d) 11 oranges e) other

4. What was the reason for your answer to question 3?

a) The number of oranges compared to the number of glasses will always be in the ratio 2 to 3.
b) If there are seven more glasses, then five more oranges are needed.
c) The difference in the numbers will always be two.
d) The number of oranges will be half the number of glasses.
e) There is no way of predicting the number of oranges.

DO NOT WRITE ON THIS SHEET



The Pendulum's Length

5. Suppose you wanted to do an experiment to find out if changing the length of a pendulum changed the amount of time it takes to swing back and forth. Which pendulums, in the above figure, would you use for the experiment?

a) 1 and 4 b) 2 and 4 c) 1 and 3 d) 2 and 5 e) all

6. What is the reason for your answer to question 5?

a) The longest pendulum should be tested against the shortest pendulum.
b) All pendulums need to be tested against one another.
c) As the length is increased the number of washers should be decreased.
d) The pendulums should be the same length but the number of washers should be different.
e) The pendulums should be different lengths but the number of washers should be the same.

The Pendulum's Weight

7. Suppose you wanted to do an experiment to find out if changing the weight on the end of the string changed the amount of the time the pendulum takes to swing back and forth. Which pendulums, in the above figure, would you use for the experiment?

a) 1 and 4 b) 2 and 4 c) 1 and 3 d) 2 and 5 e) all

8. What was the reason for your answer to question 7?

a) The heaviest weight should be compared to the lightest weight.
b) All pendulums need to be tested against one another.
c) As the number of washers is increased the pendulum should be shortened.
d) The number of washers should be different but the pendulums should be the same length.
e) The number of washers should be the same but the pendulums should be different lengths.

DO NOT WRITE ON THIS SHEET

The Vegetable Seeds

9. A gardener bought a package containing 3 squash seeds and 3 bean seeds. If just one seed is selected from the package what are the chances that it is a bean seed?

a) 1 out of 2 b) 1 out of 3 c) 1 out of 4 d) 1 out of 6 e) 4 out of 6

10. What was the reason for your answer to question 9?

a) Four selections are needed because the three squash seeds could have been chosen in a row.
b) There are six seeds from which one bean seed must be chosen.
c) One bean seed needs to be selected from a total of three.
d) One half of the seeds are bean seeds.
e) In addition to a bean seed, three squash seeds could be selected from a total of six.

The Flower Seeds

11. A gardener bought a package of 21 mixed seeds. The package contents listed:

3 short red flowers
4 short yellow flowers
5 short orange flowers
4 tall red flowers
2 tall yellow flowers
3 tall orange flowers.

If just one seed is planted, what are the chances that the plant that grows will have red flowers?

a) 1 out of 2 b) 1 out of 3 c) 1 out of 7 d) 1 out of 21 e) other

12. What was the reason for your answer to question 11?

a) One seed has to be chosen from among those that grow red, yellow or orange flowers.
b) 1/4 of the short and 4/9 of the talls are red.
c) It does not matter whether a tall or a short is picked. One red seed needs to be picked from a total of seven red seeds.
d) One red seed must be selected from a total of 21 seeds.
e) Seven of the twenty-one seeds will produce red flowers.

DO NOT WRITE ON THIS SHEET

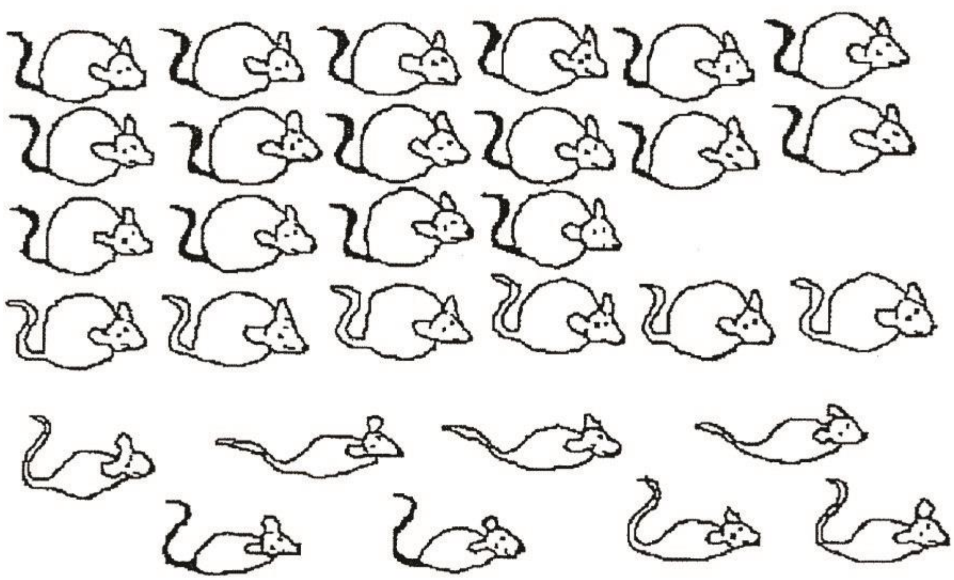
The Mice

13. The mice shown represent a sample of mice captured from a part of a field. Are fat mice more likely to have black tails and thin mice more likely to have white tails?

a) Yes   b) No

14. What is the reason for your answer to question 13?

a) 8/11 of the fat mice have black tails and 3/4 of the thin mice have white tails.
b) Some of the fat mice have white tails and some of the thin mice have white tails.
c) 18 mice out of thirty have black tails and 12 have white tails.
d) Not all of the fat mice have black tails and not all of the thin mice have white tails.
e) 6/12 of the white tailed mice are fat.



DO NOT WRITE ON THIS SHEET

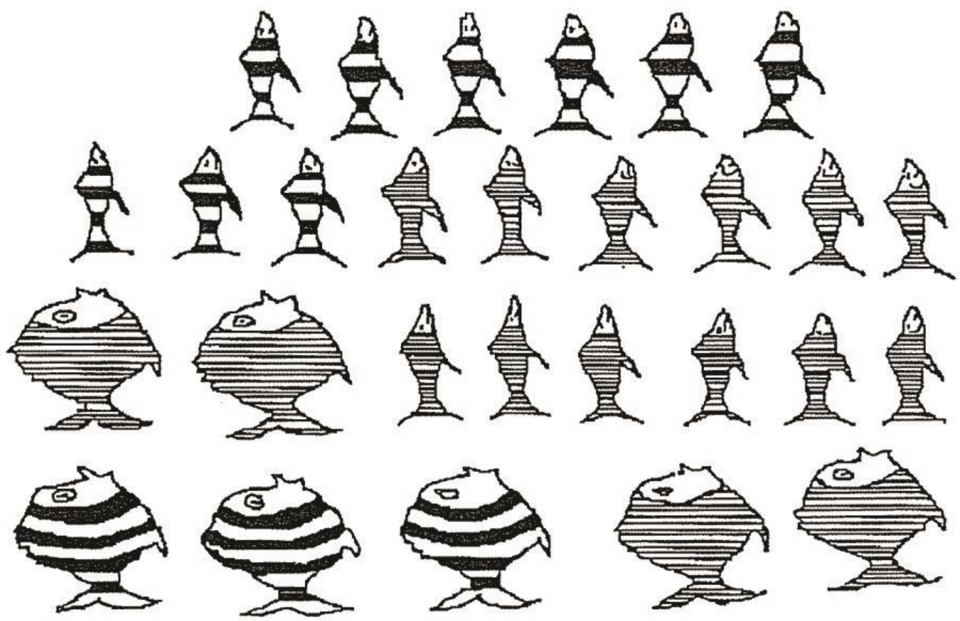
The Fish

15. Are fat fish more likely to have broad stripes than thin fish?

a) Yes b) No

16. What is the reason for your answer to question 15?

a) Some fat fish have broad stripes and some have narrow stripes.
b) 3/7 of the fat fish have broad stripes.
c) 12/28 are broad striped and 16/28 are narrow striped.
d) 3/7 of the fat fish have broad stripes and 9/21 of the thin fish have broad stripes.
e) Some fish with broad stripes are thin and some are fat.



DO NOT WRITE ON THIS SHEET

The Student Council

17. Three students from grade 10, 11, 12 were elected to the student council. A three member committee is to be formed with one person from each grade. All possible combinations must be considered before a decision can be made. Two possible combinations are Tom, Jerry and Dan (TJD) and Sally, Anne and Martha (SAM).

List all other possible combinations in spaces provided on the answer sheet. More spaces are provided on the answer sheet than you will need.

STUDENT COUNCIL

Grade 10	Grade 11	Grade 12
Tom (T)	Jerry (J)	Dan (D)
Sally (S)	Anne (A)	Martha (M)
Bill (B)	Connie (C)	Gwen (G)

The Shopping Center

18. In a new shopping center, 4 store locations are going to be opened on the ground level. A BARBER SHOP (B), a DISCOUNT STORE (D), a GROCERY STORE (G), and a COFFEE SHOP (C) want to move in there. Each one of the stores can choose any one of four locations. One way that the stores could occupy the four locations is BDGC.

List all other possible ways that the stores can occupy the 4 locations. More spaces are provided on the answer sheet than you will need.

DO NOT WRITE ON THIS SHEET

ANSWERS

Test of Logical Thinking (TOLT) Instrument

(TOLT) which was developed by Tobin and Capie (1981). The test consists of ten items measuring five reasoning modes including: proportional reasoning (items 1 & 2), controlling variables (items 3 & 4), probabilistic reasoning (items 5 & 6), correlational reasoning (items 7 & 8), and combinatorial reasoning (items 9 & 10). The items 1 to 8, consist of two parts of responding and reasoning, and to get a score of 1, students need to respond to both parts correctly. In addition, to get a score of 1 for items 9 and 10, students need to list all the possible combinations

Orange Juice #1

1. Four large oranges are squeezed to make six glasses of juice. How much juice can be made from six oranges?

a) 7 glasses b) 8 glasses c) 9 gl asses d) 1) glasses e) other

2. What was the reason for your answer to question 1?

a) The number of glasses compared to the number of oranges will always be n the ratio 3 to 2.
b) With more oranges, the difference will be less.
c) The difference in the numbers will always be two.
d) With four oranges the difference was 2. With six oranges the difference would be two more.
e) There is no way of predicting.

Orange Juice #2

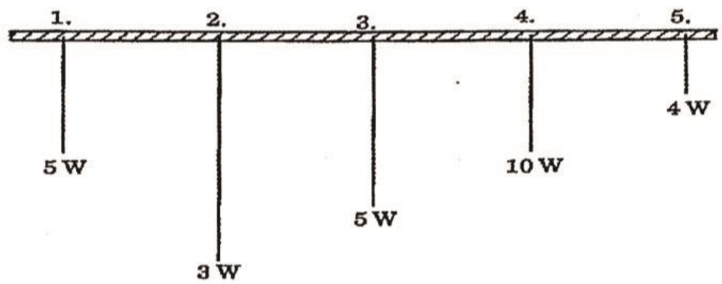
3. How many oranges are needed to make 13 glasses of juice?

a) 6 1/2 oranges b) 8 2/3 oranges c) 9 o anges d) 11 oranges e) other

4. What was the reason for your answer to question 3?

a) The number of oranges compared to the number of glasses will alw ys be in the ratio 2 to 3.
b) If there are seven more glasses, then five more oranges are needed.
c) The difference in the numbers will always be two.
d) The number of oranges will be half the number of glasses.
e) There is no way of predicting the number of oranges.

DO NOT WRITE ON THIS SHEET



The Pendulum's Length

5. Suppose you wanted to do an experiment to find out if changing the length of a pendulum changed the amount of time it takes to swing back and forth. Which pendulums, in the above figure, would you use for the experiment?

a) 1 and 4 b) 2 and 4 c) 1 and 3 d) 2 and 5 e) all

6. What is the reason for your answer to question 5?

a) The longest pendulum should be tested against the shortest pendulum.
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c) As the length is increased the number of washers should be decreased.
d) The pendulums should be the same length but the number of washers should be different.
e) The pendulums should be different lengths but the number of washers should be the same.

The Pendulum's Weight

7. Suppose you wanted to do an experiment to find out if changing the weight on the end of the string changed the amount of the time the pendulum takes to swing back and forth. Which pendulums, in the above figure, would you use for the experiment?

a) 1 and 4 b) 2 and 4 c) 1 and 3 d) 2 and 5 e) all

8. What was the reason for your answer to question 7?

a) The heaviest weight should be compared to the lightest weight.
b) All pendulums need to be tested against one another.
c) As the number of washers is increased the pendulum should be shortened.
d) The number of washers should be different but the pendulums should be the same length.
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The Vegetable Seeds

9. A gardener bought a package containing 3 squash seeds and 3 bean seeds.
If just one seed is selected from the package what are the chances that it is a bean seed?

a) 1 out of 2 b) 1 out of 3 c) 1 out of 4 d) 1 out of 6 e) 4 out of 6

10. What was the reason for your answer to question 9?

a) Four selections are needed because the three squash seeds could have been chosen in a row.
b) There are six seeds from which one bean seed must be chosen.
c) One bean seed needs to be selected from a total of three.
d) One half of the seeds are bean seeds.
e) In addition to a bean seed, three squash seeds could be selected from a total of six.

The Flower Seeds

11. A gardener bought a package of 21 mixed seeds. The package contents listed:

3 short red flowers
4 short yellow flowers
5 short orange flowers
4 tall red flowers
2 tall yellow flowers
3 tall orange flowers.

If just one seed is planted, what are the chances that the plant that grows will have red flowers?

a) 1 out of 2 b) 1 out of 3 c) 1 out of 7 d) 1 out of 21 e) other

12. What was the reason for your answer to question 11?

a) One seed has to be chosen from among those that grow red, yellow or orange flowers.
b) 1/4 of the short and 4/9 of the talls are red.
c) It does not matter whether a tall or a short is picked. One red seed needs to be picked from a total of seven red seeds.
d) One red seed must be selected from a total of 21 seeds.
e) Seven of the twenty-one seeds will produce red flowers.

DO NOT WRITE ON THIS SHEET

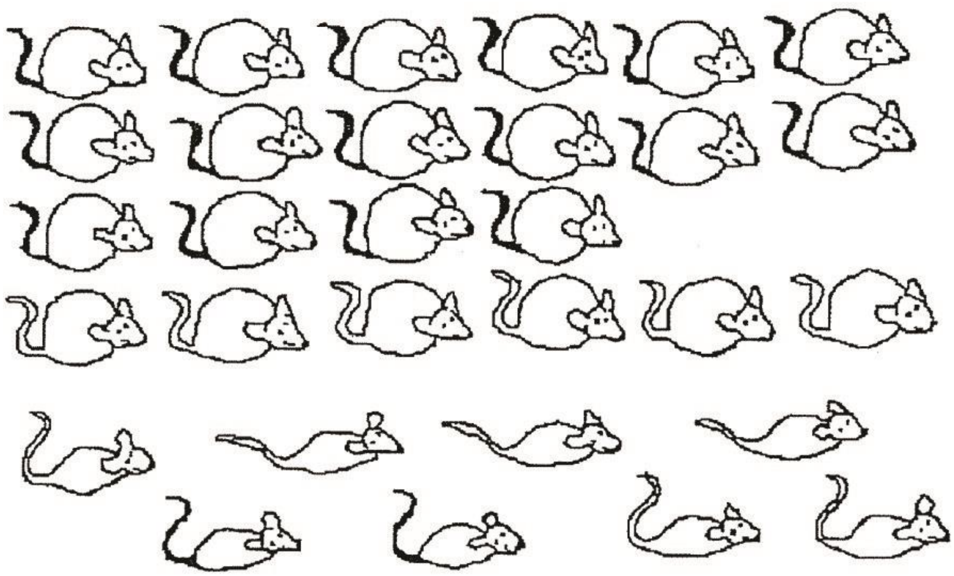
The Mice

13. The mice shown represent a sample of mice captured from a part of a field. Are fat mice more likely to have black tails and thin mice more likely to have white tails?

a) Yes b) No

14. What is the reason for your answer to question 13?

a) 8/11 of the fat mice have black tails and 3/4 of the thin mice have white tails.
b) Some of the fat mice have white tails and some of the thin mice have white tails.
c) 18 mice out of thirty have black tails and 12 have white tails.
d) Not all of the fat mice have black tails and not all of the thin mice have white tails.
e) 6/12 of the white tailed mice are fat.



DO NOT WRITE ON THIS SHEET

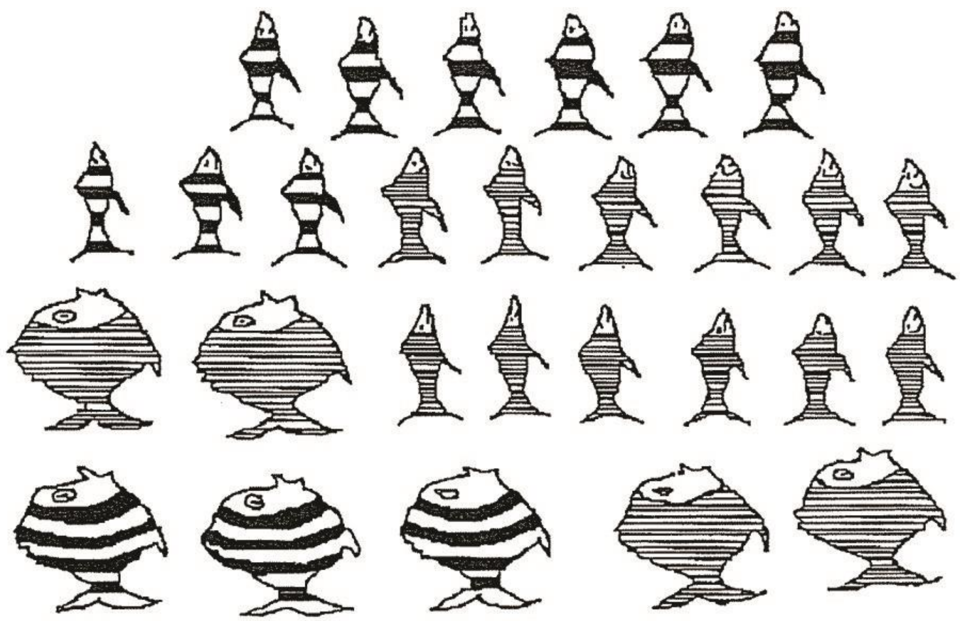
The Fish

15. Are fat fish more likely to have broad stripes than thin fish?

a) Yes b) No

16. What is the reason for your answer to question 15?

a) Some fat fish have broad stripes and some have narrow stripes.
b) 3/7 of the fat fish have broad stripes.
c) 12/28 are broad striped and 16/28 are narrow striped.
d) 3/7 of the fat fish have broad stripes and 9/21 of the thin fish have broad stripe .
e) Some fish with broad stripes are thin and some are fat.



DO NOT WRITE ON THIS SHEET

The Student Council

17. Three students from grade 10, 11, 12 were elected to the student council. A three member committee is to be formed with one person from each grade. All possible combinations must be considered before a decision can be made. Two possible combinations are Tom, Jerry and Dan (TJD) and Sally, Anne and Martha (SAM).

List all other possible combinations in spaces provided on the answer sheet. More spaces are provided on the answer sheet than you will need.

STUDENT COUNCIL

Grade 10	Grade 11	Grade 12
Tom (T)	Jerry (J)	Dan (D)
Sally (S)	Anne (A)	Martha (M)
Bill (B)	Connie (C)	Gwen (G)

TJD	TCD	TAD
TJM	TCM	TAM
TJG	TCG	TAG
SJD	SCD	SAD
SJM	SCM	SAM
SJG	SCG	SAG
BJD	BCD	BAD
BJM	BCM	BAM
BJG	BCG	BAG

Should be 27 responses

The Shopping Center

18. In a new shopping center, 4 store locations are going to be opened on the ground level. A BARBER SHOP (B), a DISCOUNT STORE (D), a GROCERY STORE (G), and a COFFEE SHOP (C) want to move in there. Each one of the stores can choose any one of four locations. One way that the stores could occupy the four locations is BDGC.

List all other possible ways that the stores can occupy the 4 locations. More spaces are provided on the answer sheet than you will need.

B D G C	D B G C	G D C B	C B D G
B D C G	D B C G	G D B C	C B G D
B G D C	D G C B	G C B D	C D B G
B G C D	D G B C	G C D B	C D G B
B C G D	D C B G	G B C D	C G B D
B C D G	D C G B	G B C D	C G D B

Should be 24 responses

DO NOT WRITE ON THIS SHEET

APPENDIX K: NASA TLX

Name:___________________________________ Project ID___________________

Category Definitions

1. Mental Demand- How much mental and perceptual activity was required (e.g. thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
2. Physical Demand- How much physical activity was required (e.g. pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
3. Temporal Demand- How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
4. Performance- How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
5. Effort- How hard di you have to work (mentally and physically) to accomplish your level of performance?
6. Frustration Level- How insecure, discouraged, irritated, stressed and annoyed v,s. secure, gratified, content, relaxed and complacent did you feel during the task

For each box circle which is the greatest source of workload between the two options

Effort or Performance	Temporal Demand or Frustration
Temporal Demand or Effort	Physical Demand or Frustration
Performance or Frustration	Physical Demand or Temporal Demand
Physical Demand or Performance	Temporal Demand or Mental Demand
Frustration or Effort	Performance or Mental Demand
Performance or Temporal Demand	Mental Demand or Effort
Mental Demand or Physical Demand	Effort or Physical Demand
Frustration or Mental Demand	

NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name	Task	Date

Mental Demand How mentally demanding was the task?

Very Low Very High

Physical Demand How physically demanding was the task?

Very Low Very High

Temporal Demand How hurried or rushed was the pace of the task?

Very Low Very High

Performance How successful were you in accomplishing what you were asked to do?

Perfect Failure

Effort How hard did you have to work to accomplish your level of performance?

Very Low Very High

Frustration How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low Very High

APPENDIX L: COLORADO LEARNING ATTITUDES ABOUT SCIENCE SURVEY

CLASS-Chemistry

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(Colorado Learning Attitudes about Science Survey)

Name: ___________________________Last 6 digits of your Student ID #: ______________

Introduction

Here are a number of statements that may or may not describe your beliefs about learning chemistry. You are asked to rate each statement by circling a number between 1 and 5 where the numbers mean the following:

1. Strongly Disagree
2. Disagree
3. Neutral
4. Agree
5. Strongly Agree

Choose one of the above five choices that best expresses your feeling about the statement. If you don't understand a statement, leave it blank. If you understand, but have no strong opinion, choose 3.

Survey

1. A significant problem in learning chemistry is being able to memorize all the information I need to know.

Strongly Disagree	1 2 3 4 5	Strongly Agree

2. To understand a chemical reaction, I think about the interactions between atoms and molecules.

Strongly Disagree	1 2 3 4 5	Strongly Agree

3. When I am solving a chemistry problem, I try to decide what would be a reasonable value for the answer.

Strongly Disagree	1 2 3 4 5	Strongly Agree

4. I think about the chemistry I experience in everyday life.

Strongly Disagree	1 2 3 4 5	Strongly Agree

5. It is useful for me to do lots and lots of problems when learning chemistry.

Strongly Disagree	1 2 3 4 5	Strongly Agree

6. After I study a topic in chemistry and feel that I understand it, I have difficulty solving problems on the same topic.

Strongly Disagree	1 2 3 4 5	Strongly Agree

7. Knowledge in chemistry consists of many disconnected topics.

Strongly Disagree	1 2 3 4 5	Strongly Agree

8. As chemists learn more, most chemistry ideas we use today are likely to be proven wrong.

Strongly Disagree	1 2 3 4 5	Strongly Agree

9. When I solve a chemistry problem, I locate an equation that uses the variables given in the problem and plug in the values.

Strongly Disagree	1 2 3 4 5	Strongly Agree

10. I find that reading the text in detail is a good way for me to learn chemistry.

Strongly Disagree	1 2 3 4 5	Strongly Agree

11. I think about how the atoms are arranged in a molecule to help my understanding of its behavior in chemical reactions.

Strongly Disagree	1 2 3 4 5	Strongly Agree

12. If I have not memorized the chemical behavior needed to answer a question on an exam, there's nothing much I can do (legally!) to figure out the behavior.

Strongly Disagree	1 2 3 4 5	Strongly Agree

13. I am not satisfied until I understand why something works the way it does.

Strongly Disagree	1 2 3 4 5	Strongly Agree

14. I cannot learn chemistry if the teacher does not explain things well in class.

Strongly Disagree	1 2 3 4 5	Strongly Agree

15. I do not expect equations to help my understanding of the ideas in chemistry; they are just for doing calculations.

Strongly Disagree	1 2 3 4 5	Strongly Agree

16. I study chemistry to learn knowledge that will be useful in my life outside of school.

Strongly Disagree	1 2 3 4 5	Strongly Agree

17. I can usually make sense of how two chemicals react with one another.

Strongly Disagree	1 2 3 4 5	Strongly Agree

18. If I get stuck on a chemistry problem on my first try, I usually try to figure out a different way that works.

Strongly Disagree	1 2 3 4 5	Strongly Agree

19. Nearly everyone is capable of understanding chemistry if they work at it.

Strongly Disagree	1 2 3 4 5	Strongly Agree

20. Understanding chemistry basically means being able to recall something you've read or been shown.

Strongly Disagree	1 2 3 4 5	Strongly Agree

21. Why chemicals react the way they do does not usually make sense to me; I just memorize what happens.

Strongly Disagree	1 2 3 4 5	Strongly Agree

22. To understand chemistry I discuss it with friends and other students.

Strongly Disagree	1 2 3 4 5	Strongly Agree

23. I do not spend more than five minutes stuck on a chemistry problem before giving up or seeking help from someone else.

Strongly Disagree	1 2 3 4 5	Strongly Agree

24. If I don't remember a particular equation needed to solve a problem on an exam, there's nothing much I can do (legally!) to come up with it.

Strongly Disagree	1 2 3 4 5	Strongly Agree

25. If I want to apply a method used for solving one chemistry problem to another problem, the problems must involve very similar situations.

Strongly Disagree	1 2 3 4 5	Strongly Agree

26. In doing a chemistry problem, if my calculation gives a result very different from what I'd expect, I'd trust the calculation rather than going back through the problem.

Strongly Disagree	1 2 3 4 5	Strongly Agree

27. In chemistry, it is important for me to make sense out of formulas before I can use them correctly.

Strongly Disagree	1 2 3 4 5	Strongly Agree

28. I enjoy solving chemistry problems.

Strongly Disagree	1 2 3 4 5	Strongly Agree

29. When I see a chemical formula, I try to picture how the atoms are arranged and connected.

Strongly Disagree	1 2 3 4 5	Strongly Agree

30. In chemistry, mathematical formulas express meaningful relationships among measurable quantities.

Strongly Disagree	1 2 3 4 5	Strongly Agree

31. We use this statement to discard the survey of people who are not reading the questions. Please select agree (not strongly agree) for this question.

Strongly Disagree	1 2 3 4 5	Strongly Agree

32. It is important for the government to approve new scientific ideas before they can be widely accepted.

Strongly Disagree	1 2 3 4 5	Strongly Agree

33. The arrangement of the atoms in a molecule determines its behavior in chemical reactions.

Strongly Disagree	1 2 3 4 5	Strongly Agree

34. Learning chemistry changes my ideas about how the world works.

Strongly Disagree	1 2 3 4 5	Strongly Agree

35. To learn chemistry, I only need to memorize how to solve sample problems.

Strongly Disagree	1 2 3 4 5	Strongly Agree

36. Reasoning skills used to understand chemistry can be helpful to me in my everyday life.

Strongly Disagree	1 2 3 4 5	Strongly Agree

37. In learning chemistry, I usually memorize reactions rather than make sense of the underlying physical concepts.

Strongly Disagree	1 2 3 4 5	Strongly Agree

38. Spending a lot of time understanding where mathematical formulas come from is a waste of time.

Strongly Disagree	1 2 3 4 5	Strongly Agree

39. I find carefully analyzing only a few problems in detail is a good way for me to learn chemistry.

Strongly Disagree	1 2 3 4 5	Strongly Agree

40. I can usually figure out a way to solve chemistry problems.

Strongly Disagree	1 2 3 4 5	Strongly Agree

41. The subject of chemistry has little relation to what I experience in the real world.

Strongly Disagree	1 2 3 4 5	Strongly Agree

42. There are times I solve a chemistry problem more than one way to help my understanding.

Strongly Disagree	1 2 3 4 5	Strongly Agree

43. To understand chemistry, I sometimes think about my personal experiences and relate them to the topic being analyzed.

Strongly Disagree	1 2 3 4 5	Strongly Agree

44. Thinking about a molecule's three-dimensional structure is important for learning chemistry.

Strongly Disagree	1 2 3 4 5	Strongly Agree

45. It is possible to explain chemistry ideas without mathematical formulas.

Strongly Disagree	1 2 3 4 5	Strongly Agree

46. When I solve a chemistry problem, I explicitly think about which chemistry ideas apply to the problem.

Strongly Disagree	1 2 3 4 5	Strongly Agree

47. If I get stuck on a chemistry problem, there is no chance I'll figure it out on my own.

Strongly Disagree	1 2 3 4 5	Strongly Agree

48. Spending a lot of time understanding <u>why</u> chemicals behave and react the way they do is a waste of time.

Strongly Disagree	1 2 3 4 5	Strongly Agree

49. When studying chemistry, I relate the important information to what I already know rather than just memorizing it the way it is presented.

Strongly Disagree	1 2 3 4 5	Strongly Agree

50. When I'm solving chemistry problems, I often don't really understand what I am doing.

Strongly Disagree	1 2 3 4 5	Strongly Agree

APPENDIX M: GAMIFICATION QUESTIONNAIRE

Name:____
Group:__________________________

Please respond in full by circling one answer in the multiple choice or writing short responses in complete sentences.

1. How frequently do you play card games and/or tabletop games?
   a. <1 time per week
   b. 2-3 times per week
   c. 4-5 times per week
   d. 6+ times per week
2. What was the relevance of playing the Gamified POGIL Activity (GPA)
   a. GPA clarified concepts that I already learned
   b. I learned new concepts playing GPA
   c. GPA didn't teach or clarify any concept
   d. None of the above. Please, explain:____
3. How was the gaming experience?
   a. I played GPA like a normal game without any intention to learn or clarify chemistry concepts
   b. I didn't enjoy playing GPA and it didn't help learn/clarify chemistry concepts
   c. I enjoyed playing GPA and it helped learn/clarify chemistry concepts
   d. None of the above. Please, explain:____
4. How easy was it to learn the game and game mechanics?
   a. It was fairly easy to learn GPA and the game mechanics are interesting
   b. It was hard to learn GPA but the game mechanics are interesting
   c. It was hard to learn GPA and the game mechanics are too complicated
   d. None of the above. Please, explain:____
5. If GPA were commercially available, would you buy it or want your professor to use it?
   a. Yes
   b. No
6. What have you learned by playing GPA?
   ____
   ____

7. Additional Comments:

   ____
   ____

Questionnaire extrapolated from Gamified study by Eduardo Triboni and Gabriel Weber J. Chem. Educ. 2018, 95, 791–803

APPENDIX N: INTERVIEW PROTOCOLS

TEL interview

Time: __:__

Date:___/____/20__

Place:____

Interviewer: Nathan Turner

Interviewee:____

Position of interviewee: __ of__

POGIL is an extensively researched, guided inquiry based approach that is proven effective in both lecture and laboratory teaching. The purpose of this project is gamification of POGIL activities (gPa) to a) increase student academic performance, b) improve student conceptual understanding, c) and foster student engagement in a large enrollment chemistry course. Two research questions will be addressed in the area of general chemistry: 1) What is the impact of gPa on student a) academic performance, b) conceptual understanding and c) engagement? 2) How do gPa encourage small group interaction & problem solving skills?

Required Disclaimer: By consenting to the study you also consented to completing the group interview. All information used in this study, both personal and private, will only be accessed by the IRB approved researcher. This includes myself and the principle investigator. Although the interview is being recorded it will only be viewed by myself during transcription and coding and will be destroyed along with other personal data at the conclusion of the study.

Questions:

I. What is your previous experience with Chemistry? Did you have any chemistry class that you took before college?

II. What is your previous experience with the following topics: Ionic Naming, Covalent Naming, Molecular Geometry, Molecular Polarity, Oxidation-Reduction Reaction and Displacement Reaction?
   a. If you have had previous experience with these topics was it difficult or fairly easy?

III. Have you ever had a group learning experience in a class? Was it helpful to your learning process, confusing, or detrimental to your learning process?

IV. In the past has your academic performance improved when working in small groups activities or working alone?

V. Did working in a lecture-based setting help you learn or clarify the topics addressed in this study?
   a. If so, do you think you would have made an attempt to work in alone to learn/clarify the topic had you not been required to or work in a group instead?

b. If not, why so?

VI. Did you feel engaged or interested in the chemistry topics taught in the lecture-based setting? Why or why not?

VII. What is your strongest critique of a lecture-based teaching method?

VIII. Any additional Comments?

POGIL interview

Time: __:__

Date:___/____/20__

Place:____

Interviewer: Nathan Turner

Interviewee:____

Position of interviewee: __ of__

POGIL is an extensively researched, guided inquiry based approach that is proven effective in both lecture and laboratory teaching. The purpose of this project is gamification of POGIL activities (gPa) to a) increase student academic performance, b) improve student conceptual understanding, c) and foster student engagement in a large enrollment chemistry course. Two research questions will be addressed in the area of general chemistry: 1) What is the impact of gPa on student a) academic performance, b) conceptual understanding and c) engagement? 2) How do gPa encourage small group interaction & problem solving skills?

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Questions:

I. What is your previous experience with Chemistry? Did you have any chemistry class that you took before college?

II. What is your previous experience with the following topics: Ionic Naming, Covalent Naming, Molecular Geometry, Molecular Polarity, Oxidation-Reduction Reaction and Displacement Reaction?
    a. If you have had previous experience with these topics was it difficult or fairly easy?

III. Have you ever had a group learning experience in a class? Was it helpful to your learning process, confusing, or detrimental to your learning process?

IV. In the past has your academic performance improved when working in small groups activities or working alone?

V. Did working in a small group help you learn or clarify the topics addressed in this study?
   a. If so, do you think you would have made an attempt to work in a small group to learn/clarify the topic had you not been required to?
   b. If not, why so?

VI. What are elements of POGIL (the group assignments) that have helped your learning/clarifying the topic?

VII. What is your strongest critique of POGIL (the group assignments)?

VIII. Any additional Comments?

GpA Interview

Time: __:__

Date:___/____/20__

Place:____

Interviewer: Nathan Turner

Interviewee:____

Position of interviewee: __ of__

POGIL is an extensively researched, guided inquiry based approach that is proven effective in both lecture and laboratory teaching. The purpose of this project is gamification of POGIL activities (gPa) to a) increase student academic performance, b) improve student conceptual understanding, c) and foster student engagement in a large enrollment chemistry course. Two research questions will be addressed in the area of general chemistry: 1) What is the impact of gPa on student a) academic performance, b) conceptual understanding and c) engagement? 2) How do gPa encourage small group interaction & problem solving skills?

Required Disclaimer: By consenting to the study you also consented to completing the group interview. All information used in this study, both personal and private, will only be accessed by the IRB approved researcher. This includes myself and the principle investigator. Although the interview is being recorded it will only be viewed by myself during transcription and coding and will be destroyed along with other personal data at the conclusion of the study.

Questions:

I. What is your previous experience with Chemistry? Did you have any chemistry class that you took before college?

II. What is your previous experience with the following topics: Ionic Naming, Covalent Naming, Molecular Geometry, Molecular Polarity, Oxidation-Reduction Reaction and Displacement Reaction?
   a. If you have had previous experience with these topics was it difficult or fairly easy?

III. Have you ever had a gamified experience in a class (an activity that is points based)? Was it helpful to your learning process, confusing, or detrimental to your learning process?

IV. In the past has your academic performance improved when working in small groups activities or working alone?

V. Did working in a small group help you learn or clarify the chemistry topics addressed in this study?
   a. If so, do you think you would have made an attempt to work in a small group to learn/clarify the topic had you not played the GPA
   b. If not, why so?

VI. When playing the gamified POGIL activity (GPA) was it easy to learn how to play or complicated?
   a. Is there a game you've played before that is similar to GPA that you enjoy?
   b. If GPA was complicated which aspects of the game make it hardest to learn? What would be your recommendation to simplify the game?

VII. What are elements of GPA that have helped your learning/clarifying the topics?

VIII. What is your strongest critique of GPA?

IX. Any additional Comments?