ASSESSING UNDERGRADUATE EXPLANATION CONSTRUCTION AND AFFECTIVE CHARACTERISTICS TOWARDS IMPROVING SUCCESS IN GENERAL CHEMISTRY

by

MOLLY B. ATKINSON

(Under the Direction of Norbert J. Pienta)

ABSTRACT

Active learning pedagogies have been shown to increase student success and improve student attitudes. Specifically, the flipped classroom approach pushes course content outside of the classroom, allowing for focus on student-student interactions as opposed to traditional lecture, while also reducing cognitive load while in the classroom. Although much research has been done on the benefits of active environments, there is little evidence concerning specific activities in these settings, particularly in undergraduate preparatory chemistry. To probe how flipping specific activities can impact student learning and attitudes, this study assessed students in a preparatory chemistry course, preceding general chemistry I, while constructing explanations in individual and group settings, utilizing the claim-evidence-reasoning (CER) framework. Students completed three CER explanations activities over the course of a semester, both individually and as small groups. During the first iteration of this study, students completed each CER activity while in class; for the second iteration, students completed the individual portion of the activity outside of class and exchanged ideas in small groups during class. Results indicate an improvement in attitudes dependent upon the semester of enrollment in the course, and that by shifting the process of individual CER explanation construction outside of the classroom, more in-class time is available for student-student interactions, leading to greater student engagement, greater chemistry content understanding, and overall better explanations of natural scientific phenomena.

INDEX WORDS: active learning, flipping the classroom, chemistry education research, constructing explanations, claim-evidence-reasoning, CER, attitudes, self-concepts, affective characteristics, constructivism, social constructivism, general chemistry, preparatory chemistry, chemistry, education, education research

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B.S., Piedmont College, 2012

A Dissertation Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirements for the Degree

DOCTOR OF PHILOSOPHY

ATHENS, GEORGIA

2018

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December 2018

DEDICATION

To my loving parents:

Mr. Charles H. Atkinson and Mrs. Teresa S. Atkinson

ACKNOWLEDGEMENTS

I would like to first and foremost acknowledge my major professor and advisor, Dr. Norbert J. Pienta, for his mentorship, guidance, support, and encouragement throughout my graduate school career. I am especially grateful for his ever-present reassurance on the tough weeks that always seem to occur when conducting research on the graduate level, to “just keep drinking your coffee and checking your email and everything will work out just fine.” I would also like to extend my gratitude to my committee members, Dr. Richard W. Morrison and Dr. Tina T. Salguero, for their direction and recommendations for this research. In addition, I thank my Pienta Lab group members, both current and former, for their feedback and suggestions during the research process. I have been fortunate to have shared a research experience with such exceptional colleagues.

I would like to extend special acknowledgements to Dr. Julie A. Luft, without whom this research would not have reached completion. My collaboration with Dr. Luft and her students Sandhya Krishnan and LaShawn McNeil was vital to these research projects. Though she was not on my committee, Dr. Luft provided unreserved advice and helpful suggestions along the way. I look up to her with ardent admiration and hope to be but half the researcher she is someday.

I am very grateful to my family for their love, understanding, and continuous support throughout my academic career. To my parents, Charles and Teresa: thank you for always pushing me to be my best and supporting me through all of life’s hills and valleys. To my sister, Abby: thank you for always seeing the silver lining in all situations, and for always being right by my side.

I would also like to pay special homage to the beverage that got me through it all: Jittery Joe’s Coffee, roasted daily in Athens, GA. I would be nothing without you.

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

Purpose

The overall objective of this research is to explore specific active learning pedagogies in a preparatory chemistry course in order to improve overall student success in general chemistry. This research explores student learning and affective characteristics in a preparatory chemistry course while constructing explanations in individual and small group settings using the claim-evidence-reasoning (CER) framework (*1*). Active learning environments benefit student learning and attitudes toward science at the collegiate level (*2*). Nonetheless, research studies on specific activities that increase conceptual learning and improve attitudes within undergraduate preparatory chemistry courses are limited. Findings from this research will provide insights into how explanation construction can help with conceptual knowledge development as well as improvement in student attitudes toward the subject of chemistry and student chemistry self-concepts. Student interest in STEM majors and careers is often negatively influenced by less than positive experiences in college-level science courses, usually due to the disparity between high school and collegiate learning expectations (*3*). In hopes to decrease the attrition rate of science majors from first year to final year of undergraduate study, this study aims to bridge the gap between these levels by using scientific practices, such as constructing explanations, emphasized by the Next Generation Science Standards (NGSS) at the K-12 level (*4;5*). By supporting chemistry learning through active learning environments that more accurately reflect and explicitly engage in scientific practices, it is the hope of this research to ensure that students leave the preparatory chemistry course with greater conceptual understanding and appreciation of the utility of chemistry (*3*).

Preparatory Chemistry

The first-year general chemistry sequence (CHEM 1211 and CHEM 1212) serves a large number of students at the University of Georgia, with a wide variety of prospective majors and career plans, and students who enroll in the first general chemistry course in this two-semester sequence enter with varying degrees of readiness for this rigorous course. High failure and withdrawal rates in CHEM 1211 led to the development of a college-level, preparatory chemistry course, CHEM 1210: Basics of Chemistry. This is a 4-credit hour course with no lab and was specifically designed to focus on basic and foundational chemistry concepts, problem-solving, and success strategies that can be applied in the general chemistry sequence, as well as other science courses on the university level. It has been shown that students who have completed CHEM 1210 in the fall generally have better success in CHEM 1211 in the spring semester than students having to repeat CHEM 1211 in the spring or students taking CHEM 1211 in the spring semester for the first time. It is important to note that this course is primarily composed of students who already feel like they have had a less than positive experience in chemistry; over half of the population of students in CHEM 1210 have dropped down from CHEM 1211 after failing the first exam in that course. It is the goal of this research to help preparatory chemistry students build conceptual knowledge of chemistry and improve their attitudes and self-concepts towards chemistry.

Theoretical Framework

Madland and Richards state that, “one of the defining features of quality educational experiences has been interaction” (*6*). Social constructivism plays a crucial role in this research and is based on the philosophy that students build their content knowledge by interacting with one another in knowledge based-settings (*7*). The roots of this theoretical framework stem from the work of Vygotsky, suggesting that groups are powerful settings for learning, and that students interact with one another within groups in ways that challenge and enhance their knowledge (*8*). Through this lens, it is important to provide students with environments and activities in which they can actively build and construct their own knowledge through experience (*9*). Through social settings, individual students are able to access information and come to an understanding of difficult concepts which they would not be able to grasp on their own accord (*10*). In addition, the deep and meaningful learning model and the Interaction Equivalency Theorem by Anderson plays an important role in this study and includes three forms of interaction: student-student, student-teacher, and student-content; this is indicated in Figure 1.1 (*11-13*). In this research specifically, it is vital that students interact with the content on an individual level so that they can develop their own explanations; when students interact with other students, as well as with the instructor, in small group settings in the classroom, productive argumentation and discourse can provide improvements in student explanations of chemistry phenomena. The goal of this research builds on the idea of experience in social settings by combining a core social constructivist framing with that of scientific practice.

The scientific practice of constructing explanations satisfies the purposes of sense-making, articulation, and persuasion (*14*). The purpose of persuasion also qualifies under the *NGSS* defined practice of argumentation; it is important to note that these practices are very similar (*4;14*). While an argument maintains the intent to persuade and convince, an explanation aims to construct knowledge, build understanding, and provide reasoning and justification for why a scientific phenomenon occurs (*15;16*). Kulatunga and coworkers define an argument as "the justification of claims with empirical evidence and reasoning" (*17*). Both argumentation and explanation have been shown to help students talk about their own internal thought processes in such a way that causes an improvement in student knowledge and conceptual understanding on the undergraduate level (*18;19*). In comparison, a lack in argumentation within the classroom has been shown to have a negative effect on science learning (*20*).

Previous research has indicated that the most difficult portion of an argument or explanation for students to construct is the reasoning or justification for the claims developed (*21-23*). In addition, it has been shown that the nature of the activity itself is important in helping students in their development of explanations as well as in their gain of conceptual understanding, and that argumentation in groups can aid students in constructing correct ideas through consensus (*24-27*). However, most of this work has been completed in K-12 environments, physical chemistry undergraduate classrooms (*28-31*). There is a current void in the literature for how explanation construction can impact undergraduate preparatory chemistry students in the classroom. In addition, it is imperative that we better understand how to collectively support students in constructing explanations, assess student explanations, and offer guidance to students on critiquing others explanations (*32;33*). It is also important to note that instructors must be educated and supported in order to teach students "about a way of learning science that is likely very different than how they learned science" (*33*).

Summary of Presented Work

This dissertation is comprised of four main research projects which support the assessment of undergraduate explanation construction and affective characteristics in order to improve success in general chemistry.

The first research project is found in Chapter 2, entitled, "Constructing Explanations in an Active Learning Preparatory Chemistry Course." This study focuses on the practice of constructing explanations in a preparatory chemistry course using the claims-evidence-reasoning (CER) framework, by exploring the following research question: *How does the scientific practice of constructing explanations impact the explanation ability and conceptual chemistry knowledge of undergraduate students in an active learning preparatory chemistry course?* This research reveals improvements in student conceptual knowledge and in student claims and evidence over time, specifically when constructing explanations in small groups.

The second research project is found in Chapter 3, entitled, "Flipping the Scientific Practice of Constructing Explanations in an Active Learning Preparatory Chemistry Course." To gain insight into how flipping can impact student learning, this study conducted assessments of students in a preparatory chemistry course engaging in explanation construction, with students completing the individual portion of the activity outside of class and exchanging ideas in small groups during the next class period in a flipped model approach. The following research question was examined: *How does flipping the individual construction of explanations outside of an active learning preparatory chemistry classroom impact group development of explanations in the classroom and students' conceptual chemistry knowledge?* Results indicate that this flipping of the CER activities allows for both improvements in both conceptual knowledge as well as explanations of chemistry phenomena.

The third research project is found in Chapter 4, entitled, "Attitudes and Self-Concepts in an Active Learning Preparatory Chemistry Course Using Explanation Construction." This study assessed students with respect to their attitudes toward the subject of chemistry as well as their chemistry self-concepts. Specifically, this research focused on the following research question:

How are student attitudes and self-concepts impacted after one semester in an active learning undergraduate preparatory chemistry course utilizing explanations activities? Results reveal improvements in student attitudes toward chemistry in only the fall semester of the study, possibly indicative of a semester effect in this population of preparatory chemistry students.

The fourth and final research project is found in Chapter 5, entitled, "Tracking General Chemistry Student Misconceptions through the Use of an Electronic Learning Tool." This study investigates using an electronic learning tool, "Spheres", to expose misconception relating to the particulate nature of matter, specifically in regard to their understanding of the meaning of subscripts and coefficients within a chemical reaction. The following research questions were analyzed: *How do students represent their understanding of the particulate nature of matter across different reaction types using an electronic learning tool (ELT), what strategies are used when looking at reactions on the molecular level within the ELT, and does the order in which the participant draws the reaction impact student understanding?* Results show that the order in which preparatory chemistry and general chemistry students draw reactions on the molecular level is significantly different.

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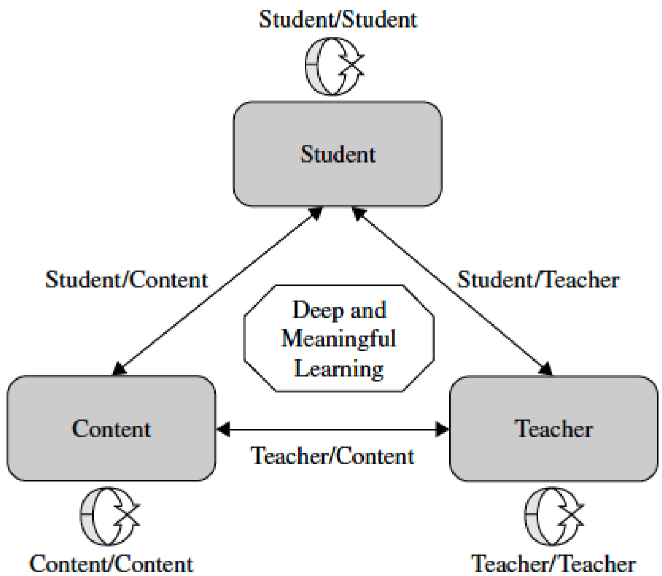
Figure 1.1: Modes of interaction for deep and meaningful learning. Three forms of interaction provide for deep and meaningful learning, namely: student-student interaction, student-teacher interaction, and student-content interaction (*11;12*).


Student/Student
Student
Student/Content
Student/Teacher
Deep and Meaningful Learning
Content
Teacher
Teacher/Content
Content/Content
Teacher/Teacher

CHAPTER 2

CONSTRUCTING EXPLANATIONS IN AN ACTIVE LEARNING PREPARATORY CHEMISTRY COURSE[1]

[1]Atkinson, M. B.; Krishnan, S.; McNeil, L. A.; Luft, J.A.; and Pienta, N. J. To be submitted to *J. Chem. Educ.*

Abstract

Active learning environments have been shown to benefit undergraduate student learning, and while much is known about how instructional approaches can support an active learning environment, there is limited evidence about how instructional methods aid in conceptual learning in undergraduate chemistry courses. The process of constructing explanations is one potential instructional approach to support conceptual learning. This study focused on the practice of constructing explanations and looked at the conceptual learning of students in a preparatory chemistry course. Using the claims-evidence-reasoning (CER) framework, the course had students engage in the explanation process of making a claim, drawing upon evidence to support the claim, and using evidence to provide reasoning for the claim through highlighting scientific concepts. Students received explicit instruction on constructing explanations and engaged in three activities through the course of a semester, with each activity focusing on a separate chemistry concept. Student data on the use of CER and conceptual learning were collected throughout the semester. Analysis of student data revealed that students did not improve in their ability to construct explanations as a whole over time; however, an improvement in student claims and evidence was seen over time, specifically when constructing explanations at the small group level of interactions. Students also significantly improved their conceptual knowledge over time. This study reveals that using a CER approach may support the conceptual learning of students, but it raises questions about how to best scaffold CER activities to elicit the development of high quality student explanations in the preparatory chemistry course setting.

Introduction

Active learning is broadly defined as an instructional strategy used to engage students in the process of constructivism, or the construction of knowledge by the students themselves, through student activity; this is directly in contrast to the passive acquisition of information provided through the traditional instructional strategy of lecture (*1*). Chickering and Gamson define the concept of active learning well: “Learning is not a spectator sport. Students do not learn much just by sitting in class listening to teachers, memorizing pre-packaged assignments, and spitting out answers. They must talk about what they are learning, write about it, relate it to past experiences, apply it to their daily lives. They must make what they learn part of themselves” (*2*). Similarly, Bonwell and Eison describe active learning with the following statement: “Students are involved in more than listening. Less emphasis is placed on transmitting information and more on developing students' skills. Students are involved in higher-order thinking (analysis, synthesis, evaluation). Students are engaged in activities (e.g., reading, discussing, writing). Greater emphasis is placed on students' exploration of their own attitudes and values” (*3*).

Freeman and coworkers report failure rates for students in an active learning environment versus students in a traditional lecture environment, indicating specifically that the mean failure rate of students is lower for those learners participating within the active learning environment; this suggests that an increase in student performance is associated with active learning classrooms in comparison to standard lecture classrooms (*1*). The element of discussion and classroom discourse is of particular importance. Social constructivism, defined as the examination of how social interactions affect the construction of student knowledge, has specifically been shown to aid students in the development of higher order thinking skills and greater conceptual understanding (*4;5*).

Active learning has been a central theme of reform in science education at the university level and has been shown to increase success, motivation, and learning gains in science courses (*6*). Active learning has also been shown to benefit the depth of student learning in diverse populations (*1;7-9*). In addition, active learning environments have been shown to encourage students to choose science majors or science careers, more so than their peers in non-active learning environments (*10;11*). Active learning environments have been successfully embedded in fields such as biology and physics, but research in undergraduate chemistry has not been as prevalent (*12*). Chemistry learning has far too often relied on traditional lecture settings to teach chemistry because of curricular restrictions and space restrictions (*9;13*). It has been shown that transforming physical space allows students to better engage with active learning practices (*14*). There have been many different active learning instructional strategies designed and developed, including student-centered active learning environment with upside-down pedagogies (SCALE-UP), which focuses on learning through social constructivism and collaboration (*15*).

SCALE-UP originated in physics, but has since branched into many other fields of study, with 314 departments in 189 higher education institutions in 21 countries having SCALE-UP classrooms; SCALE-UP instruction occurs in a highly collaborative, hands-on, technology-rich, interactive learning environment in which the classroom has been “flipped” to encompass “upside-down pedagogies” (*15*). In this learning environment, content delivery which previously took place in the classroom now takes place outside the formal learning space, allowing the students to construct their own knowledge (*16*). The basic format of the classroom includes a number of seven foot diameter round tables comprised of three groups of three students with computers and whiteboard space to discuss conceptual problems, while the instructor circulates the room to ask questions and promote discussion (*17;18*). Many studies have been done evaluating the effectiveness of this instruction methodology; overall, SCALE-UP research has shown an improvement in student ability to solve and understand conceptual problems, improvements in student attitudes toward active learning, a reduction in failure rates, and greater success rates in upper level classes (*19*-*23*).

Within active learning environments such as SCALE-UP classrooms and in chemistry courses specifically, instructors are still attempting to establish and provide specific activities that support student learning in chemistry and improve student attitudes toward chemistry. Educators have utilized various instructional approaches to support conceptual chemistry understanding, such as problem-based learning, interactive simulations, and student design of their own investigations (*24*-*26*). The Next Generation Science Standards (NGSS) support science learning through scientific practices in K-12 environments, and the scientific practices in these standards align with active learning approaches (*3;22*). Fortunately, learning at the collegiate level can also include these scientific practices, such as explanations from evidence, the use of mathematics, or communicating information.

This research focuses on specific active learning activities utilizing the scientific practice of constructing explanations, which functions as a practice essential for conceptual understanding as well as scientific literacy (*12;28;29*). In order to be able to construct a scientific explanation, students must be able to explain phenomena of the natural world and develop a meaningful chain of evidence supported by scientific reasoning, a meaningful practice as a learner of chemistry and developer of scientific thought (*30*). Many studies have been conducted on the use of explanations to support student learning in K-12 contexts (*31*-*33*). Unfortunately, the use and research of this approach is not as pronounced in undergraduate chemistry education (*12*).

Several frameworks have been developed and utilized to scaffold students while engaging in this scientific practice of constructing explanations (*34*). However, this research focuses on the claim-evidence-reasoning (CER) framework developed by Sampson and colleagues from the argument driven inquiry model, and similar to that of McNeill & Krajcik's work in younger children (*32;35*). The principle guiding the CER framework is that explanations of phenomena come from evidence that students develop themselves through engaging in inquiry activities (*36*). According to this model, an explanation consists of three components, defined as: (1) a claim, or a statement or answer to a research question, (2) evidence, or data that has been collected, analyzed, and interpreted in a way that supports the claim, and (3) reasoning, or a statement that explains the importance of the evidence with relevant scientific concepts (*35*). It is essential that the claim fits with the evidence, the evidence is supported by reasoning, the reasoning explains the evidence, and the evidence supports the claim. Explanations containing these components can help students in answering the what, how, and why of a scientific research question, engaging them in authentic scientific practice (*37*). By analyzing the data and developing claims supported by evidence and reasoning, students have more ownership of the explanations constructed and thus are more likely to be invested in the outcome of their investigation and in the communication of it (*38*).

The theoretical framework of social constructivism plays a crucial role in this study, as it states that students build their content knowledge by interacting with one another in knowledge based-settings (*39*). The roots of social constructivism stem from the work of Vygotsky, suggesting that groups were powerful settings for learning, and that students interact with one another within groups in ways that challenge and enhance their knowledge (*40*). The very act of interacting with and discussing ideas or concepts requires students to provide explanations for their understanding (*36;41*). This study builds on the idea of experience by combining a core social constructivist philosophy with that of scientific practice.

The scientific practice of constructing explanations has the potential to provide a simple, yet high impact learning activity in undergraduate chemistry courses. Specifically, this study explores the following research question:

How does the scientific practice of constructing explanations impact the explanation ability and conceptual chemistry knowledge of undergraduate students in an active learning preparatory chemistry course?

Design

This study is focuses on integrating explanation based activities into an undergraduate preparatory chemistry course and is part of a larger design-based research project (*42*). A team of five researchers engaged in two cycles of: (1) planning, (2) implementation, and (3) revision. In the planning stage, the researchers developed blueprints for the project, involving the identification of validated assessments to guide the pre- and post-measures of conceptual general chemistry knowledge (*43*). In addition, during the planning phase the research group designed three CER activities that required students to construct explanations about various chemistry phenomena. During the implementation phase of this project, the assessments and activities were used in three different class periods over the course of a semester in a small sample pilot study (n = 9), with students completing the activities both individually as well as in groups. During the revision phase of the pilot project, the students' multiple choice responses, written responses, and student feedback were examined by the research team, and the three activities were revised for use in the study.

Participants

This IRB-approved study took place at a doctoral university, designated by Carnegie classification as an institution of highest research activity, conducted in a college-level preparatory chemistry course, a 4-credit hour course preceding general chemistry I and specifically created to reduce DFW rates. The students entered the preparatory chemistry course either through enrollment in the course prior to the start of the semester or, with an extended drop/add period, enrollment in preparatory chemistry after initially enrolling in general chemistry I. A SCALE-UP room was utilized for the course, which allowed the students to work in groups of up to nine. Each round table held three computers, moveable chairs, and a large screen nearby that presented activities. The class format minimized traditional lecture from the instructor and emphasized student-student and student-instructor interactions, with the course containing one instructor and several peer-learning assistants. Signature consent for data collection was obtained for a total sample size of 65 participants, comprised of 19 males, 45 females, and one nonbinary participant.

Data Collection

At the beginning of the semester and prior to the implementation of CER activities in the course, students completed an 11-item demographic questionnaire developed by the research team and a 22-item chemistry concept inventory developed by Mulford and Robinson, both administered online and utilized for diagnostic purposes (*43*). In addition, participants completed the demographic questionnaire and concept inventory at the close of the semester. The demographic questions are shown in Figure 2.1. Due to the unique nature of the preparatory chemistry population of participants, the demographic questionnaire was administered with questions regarding sex, ethnicity, age, year classification, anticipated major, and anticipated grade in the preparatory chemistry course. Questions concerning enrollment in the course, previous chemistry courses taken, interest in chemistry, and group work preference were also included in the online survey.

Figure 2.2 illustrates these demographic categories for all participants (n = 65), both pre- and post-semester. In regard to sex, the population of participants consisted of 69% female, 29% male, and 2% other (nonbinary). In regard to ethnicity, the population was comprised of 74% white, 15% Asian, and 11% black or African American participants. With respect to age, participants were 75% 18 years old, 19% 19 years old, and 6% 17 or 20 years old. It is noted that this particular question altered slightly in regards to pre- and post-semester, as some students had a birthday that fell within the semester. The post-semester age percentages did not differ greatly, and were as follows: 3% 17 years old, 58% 18 years old, 35% 19 years old, 2% 20 years old, and 2% 21 years old. This was determined to be a representative sample of the other four sections of the CHEM 1210 preparatory chemistry course offered in that same semester. The group of participants included 92% freshman, 6% sophomores, and 2% juniors, relating to student year classification. An overwhelming 95% of these students had also taken a previous chemistry course, either in high school or through a dual-enrollment course while in high school; 5% of the population had no previous chemistry experience.

Figure 2.2 also displays enrollment information for participants in the course. The pie chart shows that only 11% of the population initially enrolled in CHEM 1210 (preparatory chemistry), while the remaining 89% initially enrolled in CHEM 1211 (general chemistry I) and moved back into CHEM 1210. Of these participants that moved, 77% moved after the first CHEM 1211 exam, while 12% moved before the first CHEM 1211 exam.

An open response question following the enrollment question qualitatively revealed reasoning behind the enrollment choices of students in this population. Those students that enrolled *initially* in CHEM 1210 mentioned their score on the Chemistry Diagnostic Test (CDT) as their reasoning for their enrollment decision. Of those that noted moving into CHEM 1210 *before* the first CHEM 1211 exam, most responded with reasoning statements involving their lack of preparation for general chemistry I, and that the course was too fast paced and they felt they needed a stronger chemistry foundation before taking general chemistry I. Some also noted that it was difficult to be co-enrolled in general chemistry and math courses in the same semester as reasoning for moving into CHEM 1210. Of those students that noted moving into CHEM 1210 *after* the first CHEM 1211 exam, most discussed that they did not feel their first exam score was at an adequate level to perform well in the remainder of the general chemistry course. Many in this enrollment category also explained their feeling of a lack of preparation and need for stronger foundational chemistry understanding as the reason for moving into CHEM 1210 after the first CHEM 1211 exam.

Three class periods over the course of a semester were selected in which to implement the CER activities, which focused on: (1) gas laws; (2) solubility; and (3) buffers. The classes in which the activities took place lasted 75-minutes each, and these CER activities are shown in Figures 2.3, 2.4, and 2.5.

At the beginning and end of each of the three class periods, participants completed a five-question multiple choice conceptual pre- and post-test which focused on the chemistry concept associated with the activity; these pre- and post-tests were administered online via

Qualtrics (*44*). The questions were pulled from the American Association for the Advancement of Science (AAAS) Science Assessment question bank, in which more than 600 items are the result of over a decade of research and test for common science misconceptions among students (*45*). The questions used for each of the three activities are shown in Figures 2.6, 2.7, and 2.8, with correct answer choices indicated with an asterisk and verified by three expert-level scientists.

Before beginning each activity, members of the research team gave a five-minute introduction to the practice of constructing explanations consisting of a claim, evidence, and reasoning, and this CER introduction remained consistent throughout the semester with respect to content delivered (*35;37*). Following CER instruction and for each of the three in-class activities, students were given a research question and data relating to chemistry phenomena. Students were asked to develop a claim, support that claim with appropriate evidence from the given data, and provide reasoning connecting the evidence to the claim of the phenomena under study using scientific concepts. Students first completed each activity individually, constructing their own individual explanation of the chemistry phenomena. Once completed, students then worked in self-selected small groups of 2-4 students to develop a cohesive small group explanation; during this time, students were encouraged to discuss their claims, evidence utilized, and reasoning components of their individual explanations. Finally, as a whole table of nine students in the SCALE-UP setting, students developed a whole table explanation. These three student levels of interaction (individual, small group, and whole table) can be seen in Figure 2.9. The sample size for each level of interaction is as follows: individual (n = 65), small group (n = 23), and whole table (n = 8). CER components of each constructed explanation from each individual or group interaction level were recorded on a pencil-and-paper form (Figure

2.10), to be later rubric scored by three members of the research team. Class discussions at the small group and whole table levels were observed by members of the research team, and the final activity was audio recorded on the small table and whole table levels of interaction for later studies involving transcription, thematic coding, and qualitative discourse analysis.

Data Analysis

Data from the five-question multiple choice conceptual pre- and post-tests were graded for correctness and studied quantitatively using one-sided paired parametric *t*-tests, as all data satisfied assumptions of normality.

In order to consistently assess each CER participant response form, an existing CER rubric was expanded, revised, and utilized for scoring; this adapted rubric can be found in Figure 2.11 (*29;31;32*). Three members of the research team rubric scored a set of selected response forms in order obtain reliable and consistent scores, ultimately achieving a high degree of inter-rater reliability with high agreement and a Cohen's $\kappa = 0.981$ (Cronbach's $\alpha = 0.997$), $p < 0.005$ (*46;47*). Once a high degree of inter-rater reliability was achieved, the research team independently scored all responses. Each explanation component with a lack of score agreement was reviewed by all three members of the research team included in the scoring process, until complete consensus was reached (*48*). These finalized rubric scores of each explanation component, as well as total rubric score, were analyzed descriptively using Sankey plots, parametric paired *t*-tests, parametric independent *t*-tests, and a 2-way ANOVA.

Results

From the demographics questionnaire, several measures were monitored from pre- to post-semester, as shown in Figure 2.2. Students' anticipated grades in the preparatory chemistry course greatly shifted in the negative direction after one semester. In the pre-semester questionnaire, 71% of all participants (n = 65) anticipated receiving a final course grade of an A, while the remaining 29% of the total population anticipated receiving a letter grade of B. However, the post-semester questionnaire results indicated the following anticipated letter grades for the final preparatory chemistry course grade: grade of A, 11%; grade of B, 63%; grade of C, 25%; and grade of D, 1%. Group work preference was also measured pre- to post-semester in this population of students, and results are shown in Figure 2.2. From the pre-semester questionnaire, it was determined that 12% of students preferred to work individually, 57% of students preferred to work in a small group of 2-3 people, and 31% of students preferred to work in a large group of 4-8 people. The same post-semester questionnaire resulted in 3% of students preferring to work individually in the course, 69% preferring to work in small groups of 2-3 people, and 28% preferring to work in large groups of 4-8 people.

In regard to student interest in the subject of chemistry, and shown in Figure 2.2, the pre-semester demographics questionnaire revealed that 5% of students were extremely interested, 26% were very interested, 48% were moderately interested, 12% were slightly interested, and 9% were not interested at all. The post-semester questionnaire highlights a shift in interest, with 8% of students being extremely interested, 10% very interested, 32% moderately interested, 24% slightly interested, and 26% not interested at all. This correlates will with shifts in the anticipated major of study results from that questionnaire. Pre- and post-semester, 62% of students anticipated a major of study in biology. However, indications of anticipated majors in chemistry, biochemistry, and engineering pre-semester were 5%, 3%, and 11%, while post-semester results indicated 2%, 2%, and 6%, respectively. The remaining percentages (19% and 28%, pre- and post-semester) are attributed to small numbers of students anticipating majors in the following areas: pre-dental, pharmaceutical sciences, animal science, pre-vet, public health, psychology, business, advertising, sports management, criminal justice, and those students that are undecided.

With respect to student development of explanation ability, total rubric score distributions (0-12, with 12 being the maximum total score possible) are shown in Figure 2.12 for all three levels of student interaction (individual, small group, and whole table) from first to final activity. At the individual participation level, the distribution shown in the histogram appears to obey rules of normality. For the first activity on the individual level (n = 65), the following percentages of each score category were recorded: score of 1 (2%), score of 2 (2%), score of 3 (17%), score of 4 (38%), score of 5 (29%), score of 6 (11%), score of 8 (2%). For the final activity on the individual level (n = 65), the following percentages of each score category were recorded: score of 1 (2%), score of 2 (4%), score of 3 (24%), score of 4 (13%), score of 5 (20%), score of 6 (16%), score of 7 (13%), score of 8 (5%), score of 9 (2%). For clarity, total scores which zero participants achieved have not been indicated in this list, and are represented by 0 % in Figure 2.12. However, at the small group and whole table levels of interaction, the distributions shown in the histogram appear to have definitive differences from first to final activity. In order to assess these differences, paired *t*-test analyses were performed. For the first activity on the small group level (n = 23), the following percentages of each score category were recorded: score of 3 (9%), score of 4 (22%), score of 5 (48%), score of 6 (13%), score of 7 (4%), score of 9 (4%). For the final activity on the small group level (n = 23), the following percentages of each score category were recorded: score of 3 (10%), score of 4 (25%), score of 5 (10%), score of 6 (20%), score of 7 (5%), score of 8 (25%), score of 9 (5%).

The error bar plot for total mean rubric scores at the individual and small group levels of interaction for the first and final CER activity is shown in Figure 2.13. Whole table mean rubric scores were not included in analyses of data. Paired *t*-test analyses results from Figure 2.13 can be seen in Table 2.1. For the individual level of interaction, the mean rubric scores for the first activity and final activity did not differ significantly (M = -0.40, SD = 1.96, $t(65) = 1.51$, $p = 0.14$). For the small group level of interaction, the mean rubric scores for the first activity and final activity did not differ significantly (M = 0.75, SD = 2.40, $t(23) = 1.40$, $p = 0.18$). These results demonstrate that no significant differences in mean rubric scores were found from the first to final activity over the course of a semester of preparatory chemistry and that scores do not significantly increase over time in the fall semester at the individual or small group levels of interaction.

In order to better compare the total rubric scores at the individual and small group levels of interactions, the change in score was also analyzed, as each small group is composed of 2-4 of those individual students. This change in score (Δ score) represents each student small group score minus the individual score. The error bar plot for Δ scores for the first and final CER activity is shown in Figure 2.14. Paired *t*-test analysis results from Figure 2.14 can be seen in Table 2.2. The mean Δ scores from first to final activity did not differ significantly over time (M = 0.47, SD = 2.59, $t(65) = 1.13$, $p = 0.27$).

In addition, Sankey plots were used to visualize student change in explanation ability, with the focus on each claim, evidence, and reasoning piece of the explanations, as well as on all three student interaction levels. These Sankey plots are shown in Figure 2.15, and indicate movement over the discrete CER activities over the course of a semester of preparatory chemistry, from first to final activity. It is important to highlight that, within the Sankey plots, the proportion of scores represented in the first activity are used as the basis for the plotting of the graph and the color indications of the graph. For example, by looking at individuals who achieved a claim score of 2 in the first activity in Figure 2.15, a portion of the individuals improved to develop more accurate claims, with a score of 4 on the final activity. However, the axes of the graph make it appear that the individuals remained stagnant in score over time, when that is not the case. In the Sankey plots, each axis shifts for each activity, as each rubric score on each axis is based on proportion of students attaining that particular score. When breaking down the total explanation scores into the three components, a general trend can be seen that individuals improve over time after three CER activities in their generation of claims and providing of evidence which accurately supports their claim, and that these improvements are heightened when students work in groups. In regard to individual reasoning, the overall findings show that students remain stagnant in their ability to reason why the evidence supports the claim, and these results can be seen even when students work in groups.

Regarding student conceptual chemistry knowledge, Table 2.3 shows paired *t*-test results of the mean difference from the pre- to post-test concept measures for each of the three CER activities throughout the course of the semester. For the CER Activity 1 (n = 56), the pre-test and post-test exhibited the following results, respectively: M = 0.56, SD = 0.23; M = 0.62, SD = 0.22. For the CER Activity 2 (n = 49), the pre-test and post-test exhibited the following results, respectively: M = 0.30, SD = 0.24; M = 0.58, SD = 0.24. For the CER Activity 3 (n = 46), the pre-test and post-test exhibited the following results, respectively: M = 0.32, SD = 0.24; M = 0.37, SD = 0.23. The paired samples within semester *t*-test resulted in significant differences from pre- to post-test measures CER Activity 1 (M = 0.06, SD = 0.24, $t(56) = 2.017$, $p = 0.049$, Cohen's $d = 0.29$), CER Activity 2 (M = 0.28, SD = 0.26, $t(49) = 7.45$, $p = 0.000$, Cohen's $d = 1.17$), and CER Activity 3 (M = 0.05, SD = 0.14, $t(46) = 2.48$, $p = 0.017$, Cohen's $d = 0.22$). Significant differences with small effect sizes (CER Activities 1 and 3) and large effect sizes

(CER Activity 2) are indicated within activities for these pre- and post-test scores, indicating that students are attaining better scores on those post-test measures in comparison to the pre-test for each activity. It is important to note that the sample size varied over time throughout the semester in regard to pre- and post-test measures, with variations occurring due to student withdrawal and/or decreased motivation to participate in conceptual measures after the activities.

Discussion

Based on the demographics questionnaire results from Figure 2.2 B, it seems that students are more realistic about their anticipated course grades and are more likely to declare anticipated majors of study unrelated to STEM degrees at the end of a semester of preparatory chemistry. Students are also less interested in the subject of chemistry as a whole. In addition, students are also more likely to want to work in small to large group settings, rather than individually, after a semester of preparatory chemistry in which they are interacting in active learning groups.

When preparatory chemistry students engaged in the scientific practice of constructing explanations, they demonstrated improved conceptual understanding. Through these highly scaffolded CER activities, preparatory chemistry students may be able to obtain a better grasp on conceptual chemistry material. Understanding chemistry concepts is but one dimension of foundational chemistry comprehension; it is also vital that students can use scientific concepts to construct explanations of that conceptual knowledge. While significant improvements in total explanation scores were not shown, improvements in student ability to make claims and provide evidence were demonstrated; however, the reasoning component of the constructed explanations did not improve. It is well documented in the K-12 literature that students have the most difficulty with this reasoning portion of explanations, and research among community college students has demonstrated this lack of improvement specifically in reasoning statements when constructing explanations (*29;49*). The lack of improvement in reasoning statements may also be indicative of the pervasive struggle for students to understand the utility of scientific practices (*12*). It has been shown that the specific configuration and type of activity has a critical impact on the level of argumentation and development of explanations, with substantial impact without teacher intervention on the reasoning portion of the explanation when students work in small groups (*50*-*52*).

It has been noted in the literature that discussion among and feedback from other students aids in student construction of knowledge that may not have been accessible to them at the individual level of student interaction (*53;54*). This may be due to the fact that general discourse in the classroom among students allows for the verbal projection of cognitive knowledge building processes involved in argumentation and the scientific practice of constructing explanations (*54;55*). A marked increase in performance at the small group level of student interaction when compared to the individual level of interaction was seen in this research study as well, indicating that students definitively gained from the collaborative experience of sharing and co-constructing their scientific explanations. This is also reflected in increased preference to work in a small group setting by the end of the semester of preparatory chemistry.

Implications

In summation, the use of very specific and highly scaffolded CER constructing explanations activities may provide students with increased chemistry concept knowledge at the college preparatory chemistry level. However, further work must be completed in order to understand how to help students improve their reasoning skills and be able to relate their claims and evidence to larger ideas and broader scientific concepts. It is critical to learn more about this unique population of students in order to better assess why their interest levels in chemistry, group work preference, anticipated course grades, and anticipated majors of study change so drastically after enrollment in this preparatory chemistry course.

Although this research reached its ultimate aims as outlined by the research question, unavoidable limitations have been acknowledged. CER Activity 2 was not included in the data analysis. This was due to the nature of that specific activity, as it was developed by the instructor of the course and not the research team. It was determined that the specific design of this activity did not align with the design of the first and final activities. This particular study focuses on change over time; thus, exclusion of the data from the second activity from analysis should not have a large effect on overall results.

In addition, there were several participants in the study who were not interested in participating by the final activity, as it was conducted relatively near the end of the semester. In future studies, the timeline of scheduling that final activity must be considered, as it ultimately impacted sample size for this population of students.

A conceptual inventory was utilized at the beginning of the semester and end of the semester in order to better understand students' conceptual growth over time for the semester (*43*). However, upon looking through this conceptual inventory, it was determined that the concepts covered do not align well with the preparatory chemistry course outline of topics covered. Thus, that data has not been included. It is imperative that a conceptual inventory be developed specifically for this population of preparatory chemistry students.

Finally, it is not clear how the whole table level of student interaction is beneficial to the students while constructing explanations during these CER activities. There did not appear to be much improvement between the small group and whole table levels of interaction; in fact, it was very difficult to convince the students to record explanations on that final whole table level after recording explanations on the two previous levels. The whole table level also took a large portion of time in class. Further research must be conducted on the individual and small group levels in order to better understand why the specific improvement shown was found between these levels of interaction. A less time consuming administration of these CER activities must also be investigated in order to better translate and apply the activities in a classroom setting.

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Table 2.1: Individual and group rubric score mean differences.

	n	M	SD	*t*
Individual Final-First Activity	65	-0.40	1.96	1.51
Group Final-First Activity	23	0.75	2.40	1.40

*p < 0.05.

Student total rubric score mean differences at the individual and small group levels between the first and final CER activities, with sample sizes of (n = 65) and (n = 23), respectively. This data was analyzed utilizing paired t-tests, with significance levels at the $p < 0.05$ level. Each of the mean differences (M) are indicated, along with sample sizes (n), standard deviations (SD), and t-values (t).

Table 2.2: Individual change in rubric score mean differences.

	n	M	SD	*t*
Final-First Activity	65	0.47	2.59	1.13
$*p < 0.05$.				

Student mean change in rubric scores (Δ score) difference between the first and final CER activities, with change in score being represented by each students' small group score minus their individual score. The sample consisted of 65 participant Δ scores, and this data was analyzed utilizing paired *t*-tests, with significance levels at the $p < 0.05$ level. The mean difference (M) is indicated, along with the sample size (n), standard deviation (SD), and *t*-value (*t*).

Table 2.3: CER activity pre- and post-test mean differences.

	n	M	SD	*t*	Cohen's *d*
CER Activity 1	56	0.06	0.24	2.01*	0.29
CER Activity 2	49	0.28	0.26	7.45**	1.17
CER Activity 3	46	0.05	0.14	2.48*	0.22

*$p < 0.05$; **$p < 0.001$.

Paired *t*-test mean difference results comparing CER activity pre- and post-test concept measures, with significance levels at the $p < 0.05$ level. The sample size varied over time throughout the semester, with variations occurring due to student withdrawal and/or decreased motivation to participate in conceptual measures after the activities. Each of the mean differences (M) are indicated, along with sample sizes (n), standard deviations (SD), *t*-values (*t*), and Cohen's *d*-values (*d*).

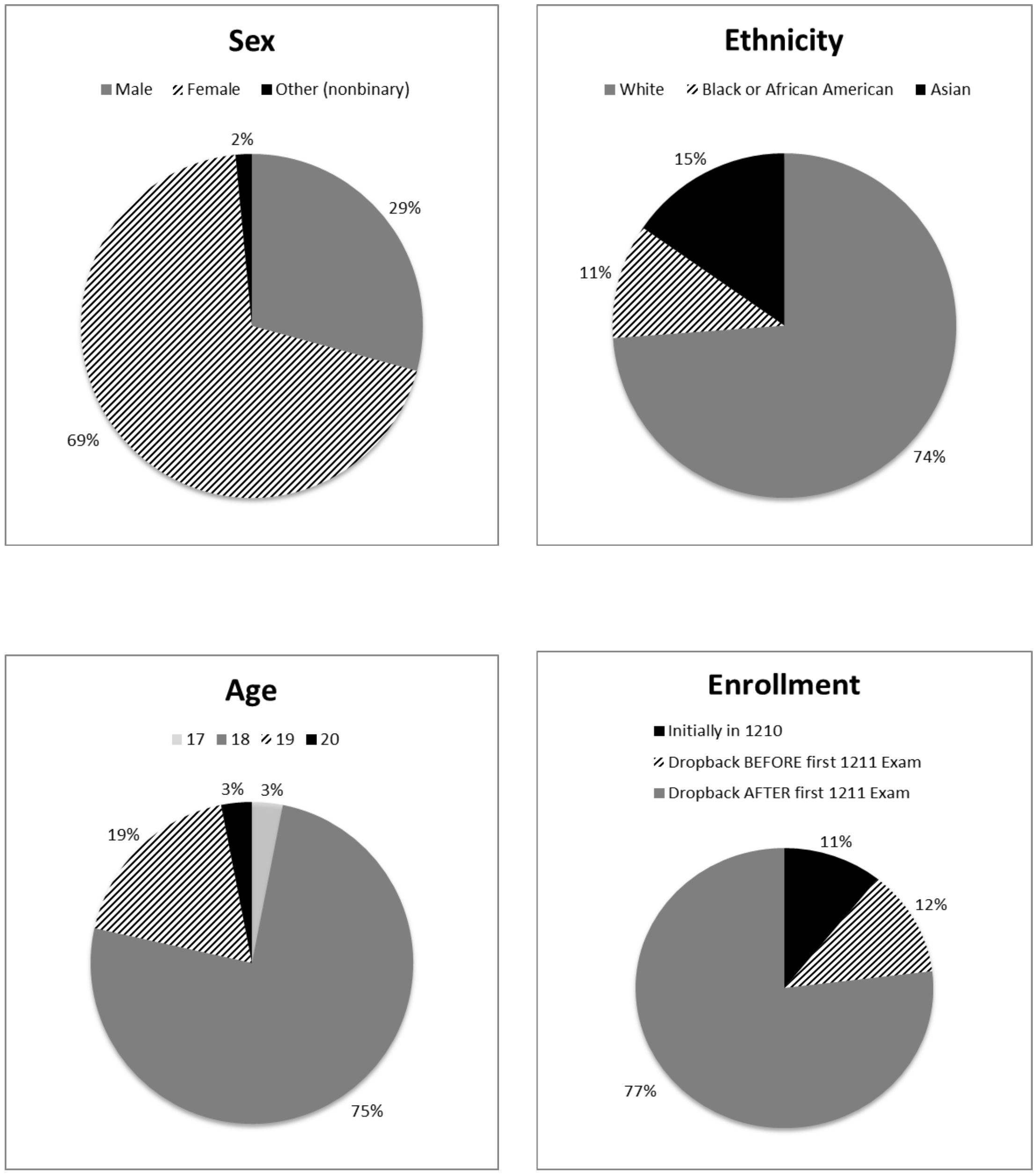
Figure 2.1: Demographics questionnaire. Questions from the 11-item demographics questionnaire were administered to participants online via Qualtrics, with questions regarding sex, ethnicity, age, year classification, anticipated major, anticipated grade in the preparatory chemistry course, enrollment in the course, previous chemistry courses taken, interest in chemistry, and group work preference (*44*).

1. To which gender do you most identify?
    a) Male
    b) Female
    c) Other (please specify)________
2. Are you of Hispanic, Latino, or Spanish origin?
    a) Yes
    b) No
3. To which racial or ethnic group(s) do you most identify? Please check all that apply.
    a) American Indian or Alaska Native
    b) Asian
    c) Black or African American
    d) Native Hawaiian or Other Pacific Islander
    e) White
4. Please indicate your age.
    a) <17
    b) 17
    c) 18
    d) 19
    e) 20
    f) 21
    g) 22
    h) 23
    i) 24
    j) 25+
5. Have you previously taken a chemistry course?
    a) No
    b) Yes, in high school
    c) Yes, in college
    d) Yes, other (please specify)
6. Which statement best describes your enrollment for Fall 2017?
    a) I initially enrolled in CHEM 1210 for Fall 2017.
    b) I enrolled in CHEM 1211 for Fall 2017 and dropped back to CHEM 1210 for Fall 2017 BEFORE the first exam. (Please explain your reason for dropback into CHEM 1210 in the space provided.)
    c) I enrolled in CHEM 1211 for Fall 2017 and dropped back to CHEM 1210 for Fall 2017 AFTER the first exam. (Please explain your reason for dropback into CHEM 1210 in the space provided.)
    d) I have taken CHEM 1210 in a previous semester. (Please indicate when you took CHEM 1210 in the space provided.)

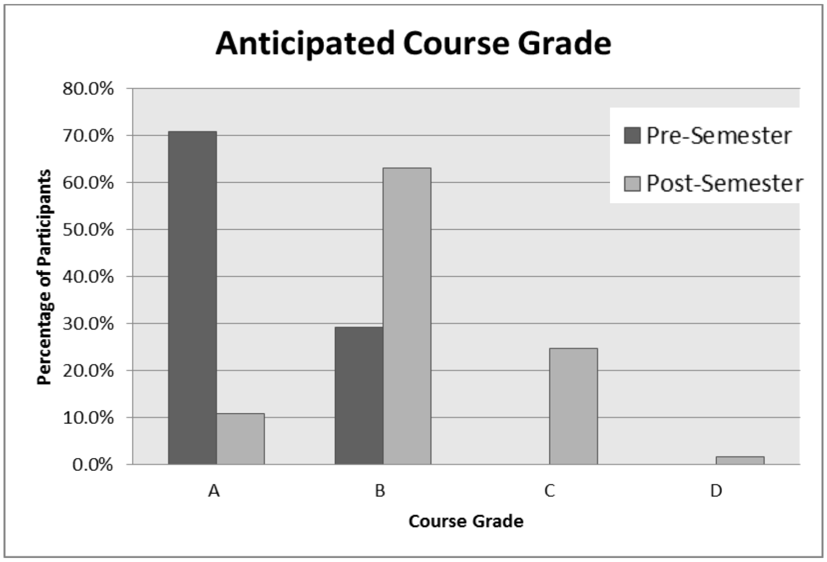
7. What is your anticipated course grade?
    a) A
    b) B
    c) C
    d) D
    e) F
8. What is your anticipated major? ____________________ (open response)
9. Please indicate your undergraduate year of study.
    a) Freshman
    b) Sophomore
    c) Junior
    d) Senior
    e) Other
10. Please rank your current level of interest in the subject of chemistry.
    a) Extremely tnterested
    b) Very interested
    c) Moderately interested
    d) Slightly interested
    e) Not interested at all
11. Which of the following best describes your ideas about group work?
    a) I would rather work with others in large groups (of 9+ people).
    b) I would rather work with others in intermediate groups (of 4-8 people).
    c) I would rather work with others in small groups (of no more than 3 people).
    d) I would rather work alone.

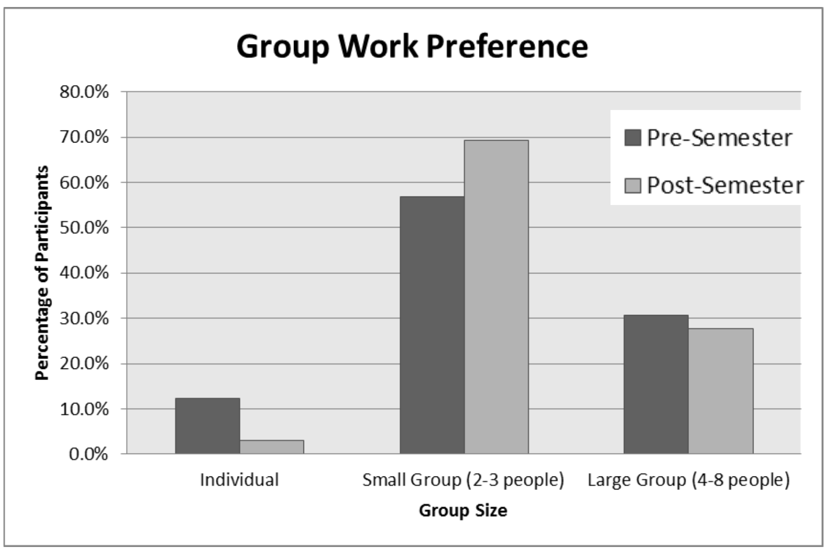
Figure 2.2: Demographic questionnaire participant results. (A) Total participant demographics (n = 65) concerning sex, ethnicity, age and enrollment information. Each pie chart is labeled with its own individual legend and percentages of represented categories. These particular survey questions remained consistent from pre- to post-semester, with the exception of age. As the age pie chart was only altered by those students who had a birthday within the semester, only the pre-semester age results have been shown. (B) Survey results for participants' change after one semester of preparatory chemistry for their anticipated course grade, group work preferences, and interest in chemistry from pre- to post-semester, indicated by dark gray and light gray bars, respectively (n = 65).

A


Sex
Male
Female
Other (nonbinary)
2%
29%
69%
Ethnicity
White
Black or African American
Asian
15%
11%
74%
Age
17
18
19
20
3%
3%
19%
75%
Enrollment
Initially in 1210
Dropback BEFORE first 1211 Exam
Dropback AFTER first 1211 Exam
11%
12%
77%

B


Anticipated Course Grade
80.0%
70.0%
60.0%
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
Percentage of Participants
A
B
C
D
Course Grade
Pre-Semester
Post-Semester


Group Work Preference
80.0%
70.0%
60.0%
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
Percentage of Participants
Individual
Small Group (2-3 people)
Large Group (4-8 people)
Group Size
Pre-Semester
Post-Semester

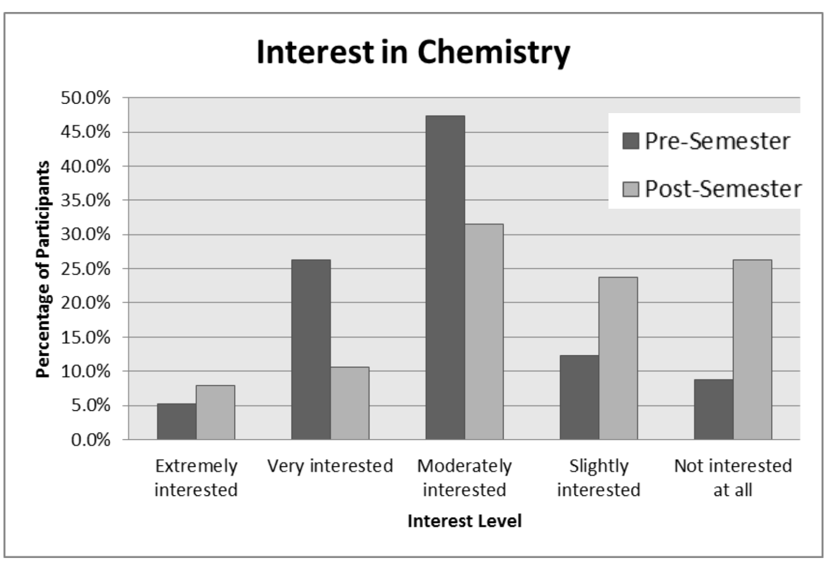

Interest in Chemistry
50.0%
45.0%
40.0%
35.0%
30.0%
25.0%
20.0%
15.0%
10.0%
5.0%
0.0%
Percentage of Participants
Extremely interested
Very interested
Moderately interested
Slightly interested
Not interested at all
Interest Level
Pre-Semester
Post-Semester

Figure 2.3: Constructing Explanations CER Activity 1. The first CER activity concerns the chemistry concept of gas laws, using the American Football League scandal “Deflategate”, in which the New England Patriots played the Indianapolis Colts (*56*). During halftime, it was determined that the Patriots’ footballs had fallen below the permissible inflation range and were re-inflated to bring them back up to the appropriate level. This activity has students look critically at the cause of the football deflation, and whether or not this deflation was due to weather conditions or foul-play. This activity was administered and displayed to students via a projection system in the classroom.

On 01/18/15, the New England Patriots and Indianapolis Colts played in the AFC Championship Game to determine which team would advance to Super Bowl XLIX. During the first half of the game, the Colts brought up the concern that the inflation levels of the Patriots' footballs were unfairly too low.

The required pressure level range is between **12.5-13.5 pounds** per square inch gauge pressure (psig). Pre-game, halftime, and post-game measurements for five of the footballs from each team are shown below. When officials measured lower levels at halftime, all footballs under the permissible range of 12.5-13.5 psig were **inflated to 12.50** psig.

Were the Patriots' footballs unfairly deflated between the pre-game and halftime measurements?

Pre-Game Measurements (71°F in locker room)		
Patriots' Footballs	**Game Official 1 Measurements (psig)**	**Game Official 2 Measurements (psig)**
1	12.50	12.55
2	12.55	12.60
3	12.55	12.50
4	12.60	12.50
5	12.65	12.55
Colts' Footballs	**Game Official 1 Measurements (psig)**	**Game Official 2 Measurements (psig)**
1	13.10	12.90
2	13.20	12.85
3	12.90	13.15
4	12.90	13.00
5	13.00	13.10

Halftime Measurements (48°F on the field)		
Patriots' Footballs	**Game Official 1 Measurements (psig)**	**Game Official 2 Measurements (psig)**
1	10.50	10.90
2	10.85	11.20
3	10.90	11.35
4	10.80	11.10
5	10.75	11.30
Colts' Footballs	**Game Official 1 Measurements (psig)**	**Game Official 2 Measurements (psig)**
1	12.70	12.35
2	12.75	12.30
3	12.50	12.95
4	12.60	12.50
5	12.70	12.50

Post-Game Measurements (71°F in locker room)		
Patriots' Footballs	**Game Official 1 Measurements (psig)**	**Game Official 2 Measurements (psig)**
1	13.50	13.15
2	13.35	12.95
3	13.35	12.95
4	13.40	13.00
5	13.45	13.10
Colts' Footballs	**Game Official 1 Measurements (psig)**	**Game Official 2 Measurements (psig)**
1	12.90	12.50
2	12.45	12.40
3	12.80	13.10
4	12.70	12.90
5	13.00	13.10

Figure 2.4: Constructing Explanations CER Activity 2. The second CER activity concerns the chemistry concept of solubility. Students are given solubility rules and two beakers of ions in water and are asked to identify the compounds which could be in each beaker, along with the result of mixing the two beakers of aqueous solutions (*57*). This activity was administered and displayed to students via a projection system in the classroom.

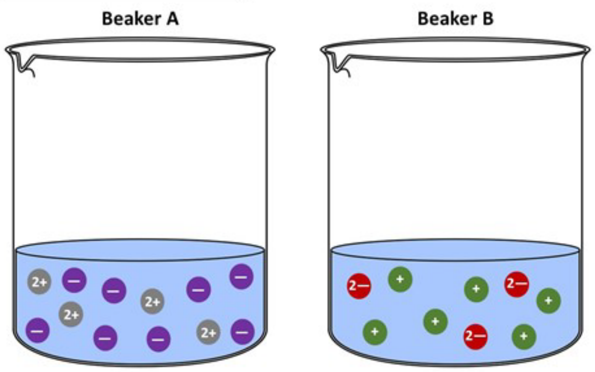


Table 5-8. Solubility Rules for Some Common Salts in Water

Salts with these ions are generally soluble	Exceptions
Li^+, Na^+, K^+, NH_4^+	none
NO_3^-, $CH_3CO_2^-$	none
Cl^-, Br^-, I^-	Salts with Pb^{2+}, Ag^+ are insoluble.
SO_4^{2-}	Salts with Ba^{2+}, Pb^{2+}, Ca^{2+}, Ag^+ are insoluble.
Salts with these ions are generally insoluble	**Exceptions**
HO^- and S^{2-}	Salts with Li^+, Na^+, K^+, NH_4^+ are soluble. HO^- salts with Ba^{2+}, Ca^{2+} are slightly soluble. S^{2-} salts with Ba^{2+}, Ca^{2+} are soluble.
CO_3^{2-}, PO_4^{3-}	Salts with Li^+, Na^+, K^+, NH_4^+ are soluble.

1. Using the list below:

$Zn(NO_3)_2$	K_2CO_3
KCl	CaS
$Pb(CO_2CH_3)_2$	Li_2SO_4
$AlPO_4$	Na_2SO_4
$MgCl_2$	$(NH_4)_2CO_3$

a. Identify the compound(s) that could be dissolved in Beaker A.

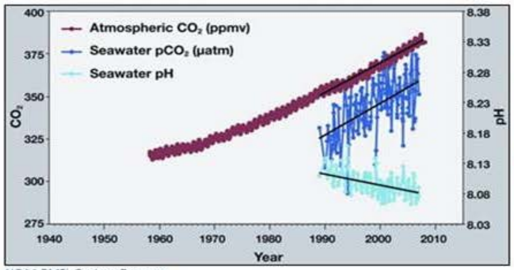
b. Identify the compound(s) that could be dissolved in Beaker B.

2. Identify potential insoluble precipitates in Beakers A and B.

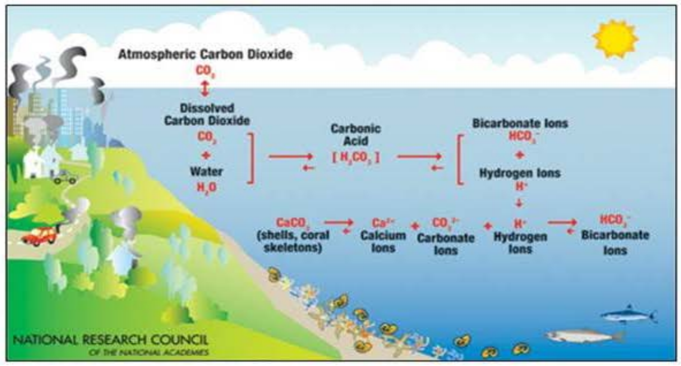
3. Identify the compound(s) that could be dissolved when you mix Beaker A and Beaker B. Your evidence should demonstrate the molecular interactions.

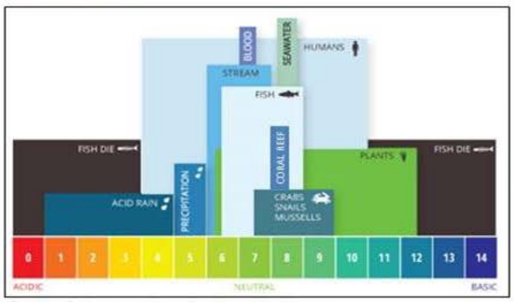
Figure 2.5: Constructing Explanations CER Activity 3. The third CER activity concerns the chemistry concept of buffers, specifically the buffering capacity of ocean water. Students are given data relating to atmospheric CO_2 levels, dissolved CO_2 levels within seawater, and seawater pH levels over time. They are also given information concerning chemical reactions involving the dissolving of atmospheric carbon dioxide into seawater, relative pH levels necessary for a range of living species, and a graph related to saturation state of aragonite (a form of calcium carbonate) over time (*58-62*). There are many factors involved when considering ocean buffering and how atmospheric CO_2 levels are affecting this complicated buffering system. This activity was administered and displayed to students via a projection system in the classroom.

The oceans are habitat to a great many of the planet's species. As such, the oceans must have the capacity to balance levels of gases in water. Use the data below and what you know of acid-base chemistry to **explain the trend in the buffering capacity of ocean water**. Make a claim, support that claim with evidence from the data, and provide your reasoning.

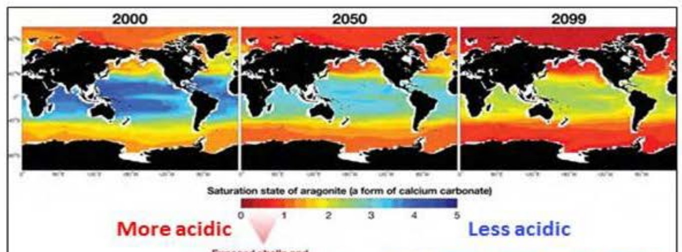


NOAA PMEL Carbon Program





Fondriest Environmental Water Quality and pH of Water



NOAA Ocean and Great Lakes Acidification Research Plan

Figure 2.6: CER Activity 1 pre- and post-test questions. The questions on the pre- and post-tests for the first activity involve conceptual, multiple-choice questions related to the chemistry concept of gas laws. These items were pulled from a test bank and administered online to participants before and after the activity via Qualtrics (*44*). Correct answers were verified by three expert-level scientists and are indicated by the asterisk (*).

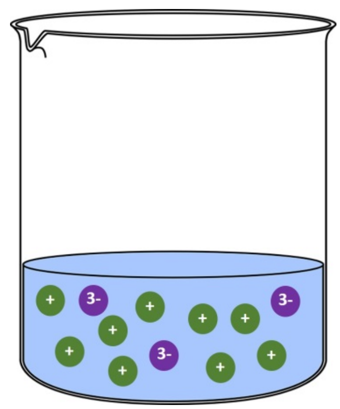
1. You are driving in your car through Athens, GA on a hot and sunny day in August. What happens to the tires of your car, relative to driving in February?
    a) Tire pressure increases.*
    b) Tire pressure stays the same.
    c) Tire pressure decreases.
    d) The tire pressure cannot be determined.
2. Which indicates the correct relationship when considering the variables of pressure, temperature, and volume?
    a) Pressure is directly proportional to temperature.*
    b) Pressure is directly proportional to volume.
    c) Pressure is inversely proportional to temperature.
    d) Temperature is inversely proportional to volume.
3. What happens to the temperature of a gas when it is compressed?
    a) The temperature increases.
    b) The temperature stays the same.*
    c) The temperature decreases.
    d) The temperature becomes unpredictable.
4. The pressure of a gas will ____ when the volume is decreased and will ____ when the temperature is decreased, respectively.
    a) increase, increase
    b) increase, decrease*
    c) decrease, increase
    d) decrease, decrease
5. If a balloon is heated, what happens to the pressure of the air inside the balloon if the volume remains constant?
    a) The pressure increases.*
    b) The pressure stays the same.
    c) The pressure decreases.
    d) The change cannot be predicted.

Figure 2.7: CER Activity 2 pre- and post-test questions. The questions on the pre- and post-tests for the second activity involve conceptual, multiple-choice questions related to the chemistry concept of solubility. These items were pulled from a test bank and administered online to participants before and after the activity via Qualtrics (*44*). Correct answers were verified by three expert-level scientists and are indicated by the asterisk (*).

Table 5-8. Solubility Rules for Some Common Salts in Water

Salts with these ions are generally soluble	Exceptions
Li^+, Na^+, K^+, NH_4^+	none
NO_3^-, $CH_3CO_2^-$	none
Cl^-, Br^-, I^-	Salts with Pb^{2+}, Ag^+ are insoluble.
SO_4^{2-}	Salts with Ba^{2+}, Pb^{2+}, Ca^{2+}, Ag^+ are insoluble.
Salts with these ions are generally insoluble	**Exceptions**
HO^- and S^{2-}	Salts with Li^+, Na^+, K^+, NH_4^+ are soluble. HO^- salts with Ba^{2+}, Ca^{2+} are slightly soluble. S^{2-} salts with Ba^{2+}, Ca^{2+} are soluble.
CO_3^{2-}, PO_4^{3-}	Salts with Li^+, Na^+, K^+, NH_4^+ are soluble.

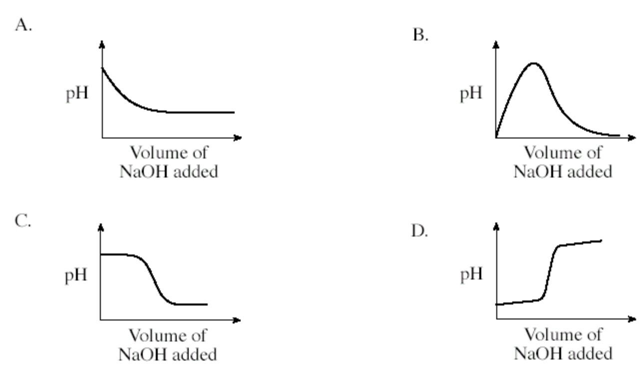
1. Which of the following compounds is soluble in water?
   a) $CaSO_4$
   b) AgCl
   c) BaS*
   d) $Mg(OH)_2$
   e) $Fe_3(PO4)_2$
2. Which of the following will occur when solutions of $CuSO_4$(*aq*) and $BaCl_2$(*aq*) are mixed?
   a) A precipitate of $CuCl_2$ will form.
   b) A precipitate of $CuSO_4$ will form.
   c) A precipitate of $BaSO_4$ will form.*
   d) A precipitate of $BaCl_2$ will form.
   e) No precipitate will form.
3. Identify the compound(s) that could be dissolved in the following beaker of water. (Select all that apply)
   a) Ag_3PO_4
   b) Na_3PO_4*
   c) $Ca_3(PO_4)_2$
   d) Li_3PO_4*
   e) None of these



4. Which of the following will occur when solutions of $Zn(NO_3)_2$(*aq*) and K_2CO_3(*aq*) are mixed?
   a) A precipitate of $ZnCO_3$ will form.*
   b) A precipitate of $Zn(NO_3)_2$ will form.
   c) A precipitate of K_2CO_3 will form.
   d) A precipitate of KNO_3 will form.
   e) No precipitate will form.
5. When two soluble compounds are mixed in solution, what will occur?
   I. The compounds will separate into their ionic components.
   II. Any new compounds formed will be insoluble and form a precipitate.
   III. Any new compounds formed will be soluble.
   IV. The soluble or insoluble nature of any new compounds formed depends on the elements that make up the original compounds.
   a) I and II   b) I and III
   c) II and III   c) I and IV*

Figure 2.8: CER Activity 3 pre- and post-test questions. The questions on the pre- and post-tests for the third activity involve conceptual, multiple-choice questions related to the chemistry concept of buffers. These items were pulled from a test bank and administered online to participants before and after the activity via Qualtrics (*44*). Correct answers were verified by three expert-level scientists and are indicated by the asterisk (*).

1. A solution containing 10^{-8}M HCl and 10^{-8}M acetic acid contains H^+ which is supplied mostly by
    a) the strong acid.
    b) the weak acid.
    c) both the strong and the weak acids.
    d) water.*
2. Compare solution A with pH=4 to solution B with pH=6.
    a) The concentration of the hydronium ion in solution A is twice that in solution B.
    b) Solution A has greater buffering capacity than solution B.
    c) The concentration of the hydronium ion in solution A is 100 times that in solution B.*
    d) The hydronium ion concentrations are equal in the two solutions since pH only measures the concentration of H^+.
3. Which of the following is the conjugate acid of the hydrogen phosphate ion, HPO_4^{2-}?
    a) H_3PO_4
    b) $H_2PO_4^-$*
    c) PO_4^{3-}
    d) H_3O^+
4. Which one of the following is not a conjugate acid-base pair?
    a) NH_3 AND NH_4^+
    b) H_3O^+ and OH^-*
    c) $H_2PO_4^-$ and HPO_4^{2-}
    d) HS^- and H_2S
    e) NH_3 and NH_2^-
5. Which of the following graphs describes the relationship between the pH of a buffer and the volume of NaOH added to the buffer?



    a) Graph A
    b) Graph B
    c) Graph C
    d) Graph D*

Figure 2.9: Student levels of interaction during the CER activities. Students first constructed an individual explanation for each activity, then worked in self-selected small groups of 3 students to develop a cohesive small group explanation, and finally, as a whole table of 9, students developed a whole table explanation. These levels of interaction are indicated at each table in the figure as a solid black circle. For this study, the sample sizes for each level of interaction are as follows: individual (n = 65), small group (n = 23), and whole table (n = 8).

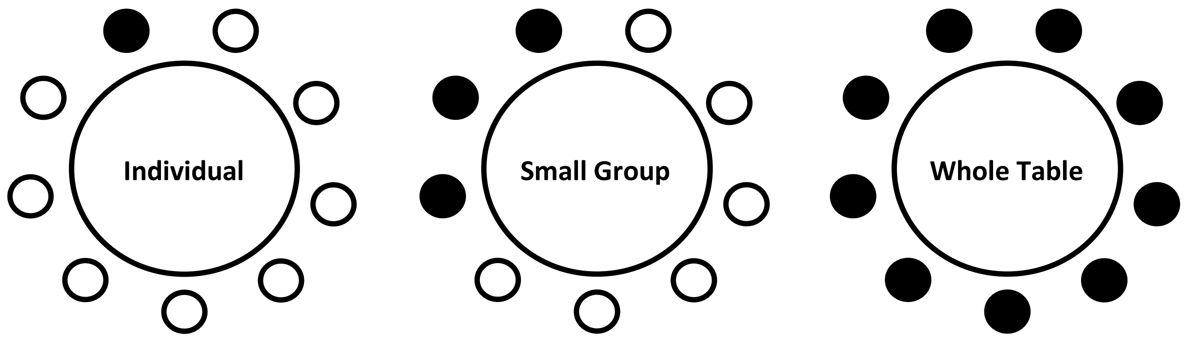

Individual
Small Group
Whole Table

Figure 2.10: Constructing Explanations CER activity participant response form. Students were given a research question and accompanying data and were required to develop a claim, support that claim with appropriate evidence from the data given, and provide reasoning for how that evidence supported the claim using scientific principles and concepts. All participant responses were recorded on the pencil-and-paper forms for all levels of interaction separately.

Research Question:

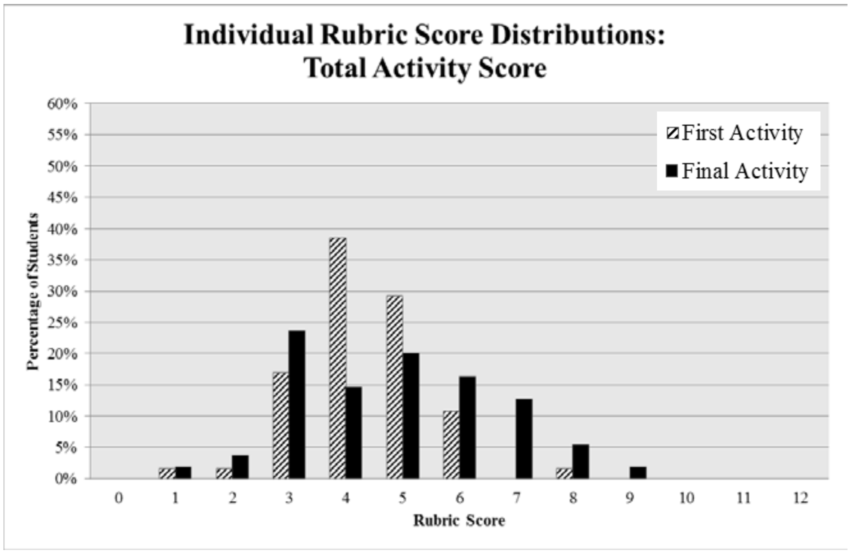
Claim:

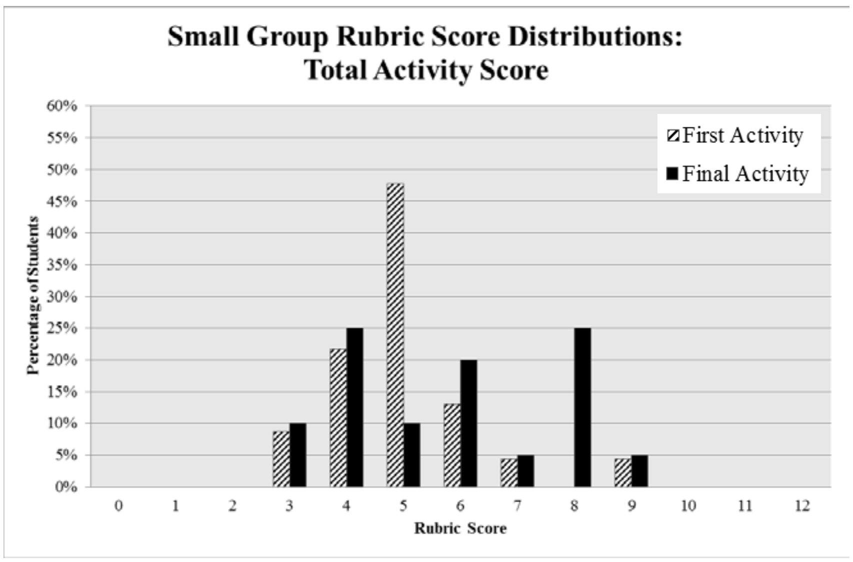
Evidence:	**Reasoning:**

Figure 2.11: Constructing Scientific Explanations Rubric. An existing CER rubric was expanded, revised, and utilized for scoring by the members of the research team (*29;31;32*). This rubric consists of a maximum total explanation score of 12, with a maximum score of 4 possible for each portion of the explanation (claim, evidence, and reasoning). Each piece is defined within the rubric, with importance placed on scientific accuracy as well as sufficiency of information.

	Claim – a statement that answers the original question	**Evidence** – data and/or patterns, trends, and/or inferences from the data that justify the claim	**Reasoning --** uses scientific ideas to explain how or why the evidence supports the claims
4	• Scientifically accurate and addresses the phenomena • Sufficient in acknowledging the critical factors	• The data are scientifically appropriate to support the claim. • The data are thorough and convincing – enough details and evidence are provided • May also show with evidence why alternate claims are not appropriate	• Reasoning clearly links all of the evidence to the claim. • The discussion of key ideas is accurate and based upon the data provided. • The key scientific ideas discussed are comprehensive.
3	• Scientifically accurate and addresses the phenomena • Partially sufficient in that more (or fewer) critical factors are provided than are needed	• The data are scientifically appropriate to support the claim. • The data are sufficient and convincing, but additional data could be provided.	• Reasoning clearly links all of the evidence to the claim. • Includes related science ideas, but may not make a direct or complete connection • The scientific ideas are accurate but are not discussed comprehensively.
2	• Partially scientifically accurate (broadly or indirectly addresses the phenomena) • Partially sufficient in that more (or fewer) critical factors are provided than are needed	• The data relate broadly or indirectly to the claim. • The data are not sufficient and additional data should be provided.	• Reasoning links some of the evidence to the claim. • Includes related science ideas, but may not make a direct or complete connection • The scientific ideas are not accurate or may not be discussed comprehensively.
1	• Not scientifically accurate (does not address the phenomena) • Does not adequately answer the question	• There is some evidence provided, but it is not logically linked to the claim nor is it scientifically appropriate.	• Few or no links of evidence to the claim • The discussion of key ideas is limited or absent.
0	• No claim provided	• No evidence provided	• No reasoning provided

Figure 2.12: CER activity total rubric score distributions. These distributions are shown for percentage of students attaining each possible total rubric score category (0-12, with 12 being the maximum score possible), from first activity (indicated by the striped bars) to final activity (indicated by the solid bars). Distributions have been included for the individual, small group, and whole table levels of interaction.


Individual Rubric Score Distributions:
Total Activity Score
First Activity
Final Activity
Percentage of Students
Rubric Score
60%
55%
50%
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
0
1
2
3
4
5
6
7
8
9
10
11
12


Small Group Rubric Score Distributions:
Total Activity Score
First Activity
Final Activity
Percentage of Students
Rubric Score
60%
55%
50%
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
0
1
2
3
4
5
6
7
8
9
10
11
12

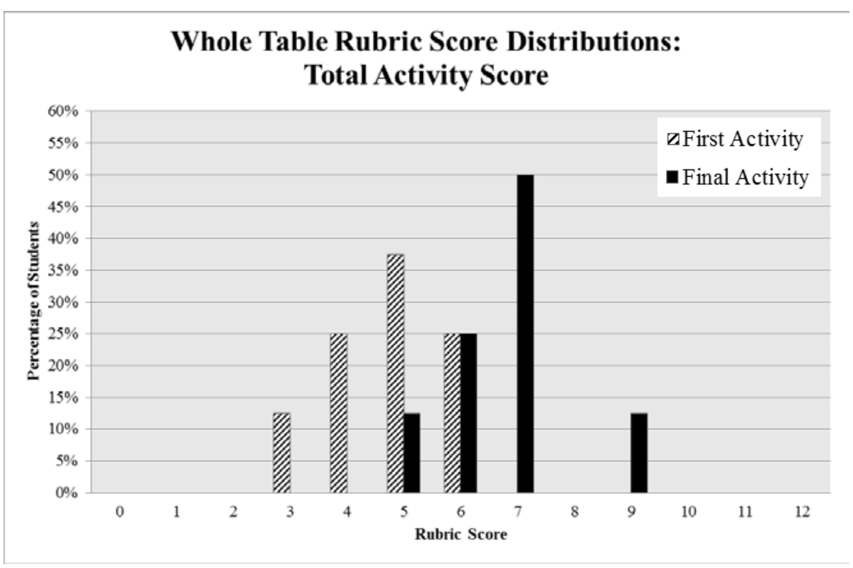
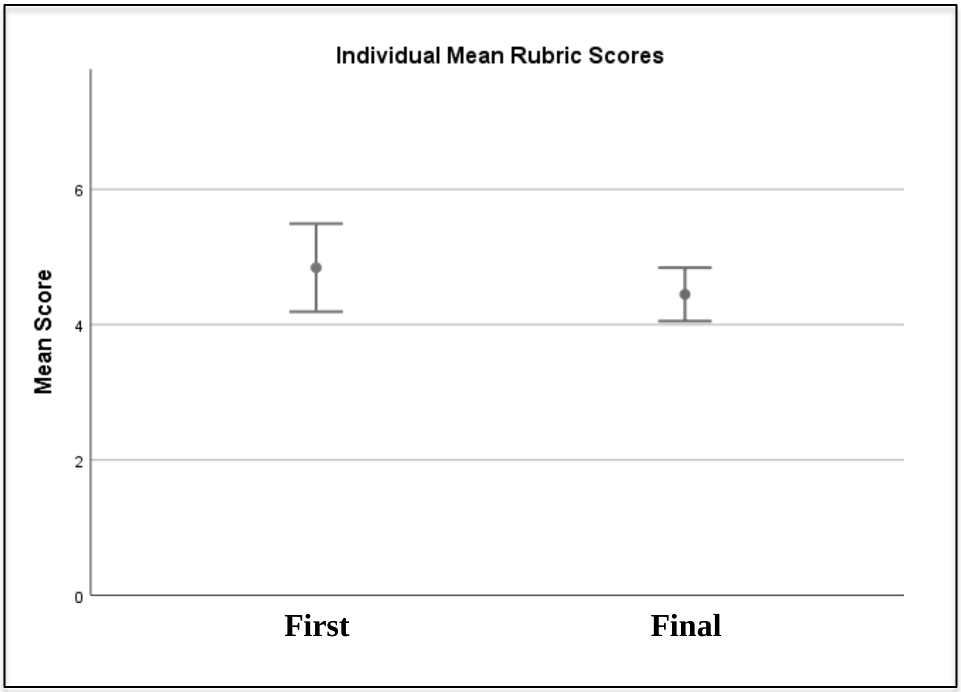

Whole Table Rubric Score Distributions:
Total Activity Score
First Activity
Final Activity
Percentage of Students
Rubric Score
60%
55%
50%
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
0
1
2
3
4
5
6
7
8
9
10
11
12

Figure 2.13: Mean total rubric scores over time. Student mean total rubric scores are indicated at the individual and small group levels of interaction for the first and final CER activities. Error bars are indicated at the 95% confidence interval. Whole table mean rubric scores were not included in analyses of data.


Individual Mean Rubric Scores
Mean Score
0
2
4
6
First
Final

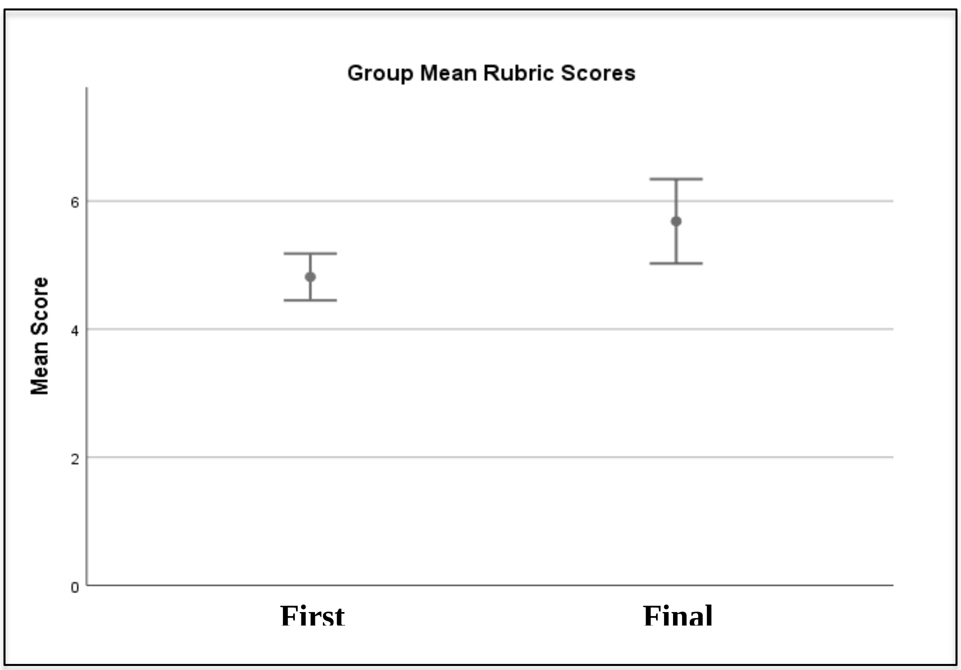

Group Mean Rubric Scores
Mean Score
0
2
4
6
First
Final

Figure 2.14: Change in mean rubric scores. Each student's change in mean total rubric score (Δ score) for the first and final CER activities was analyzed, with the Δ score being represented by each student's small group score minus their individual score. Error bars are indicated at the 95% confidence interval.

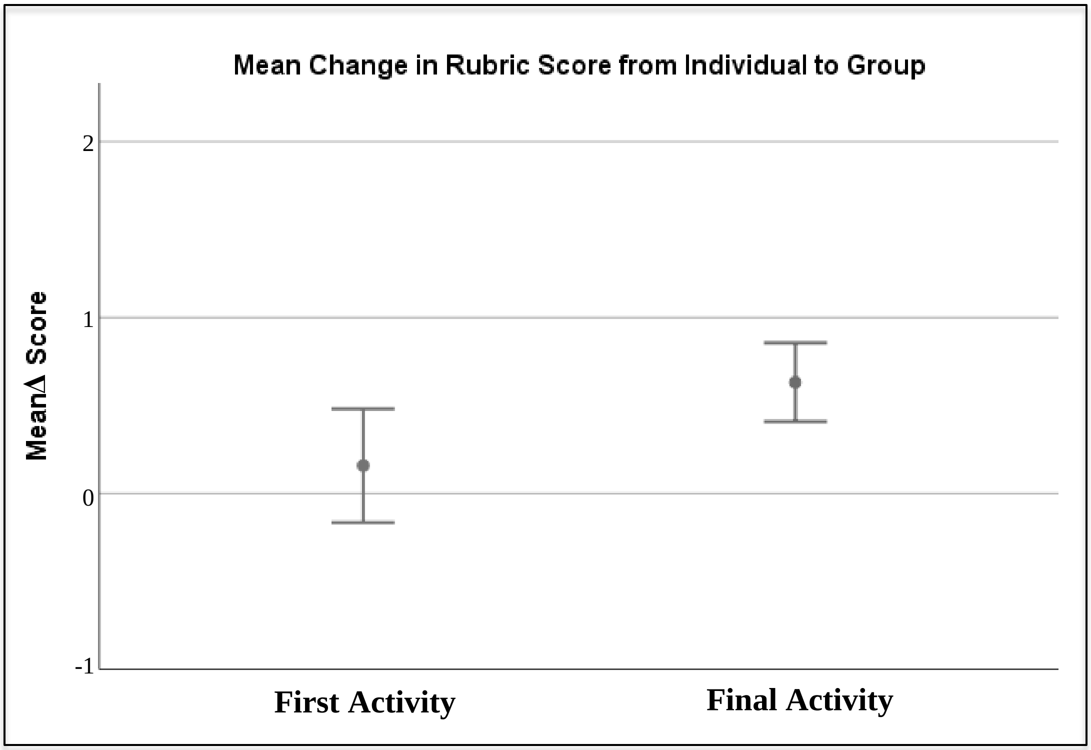
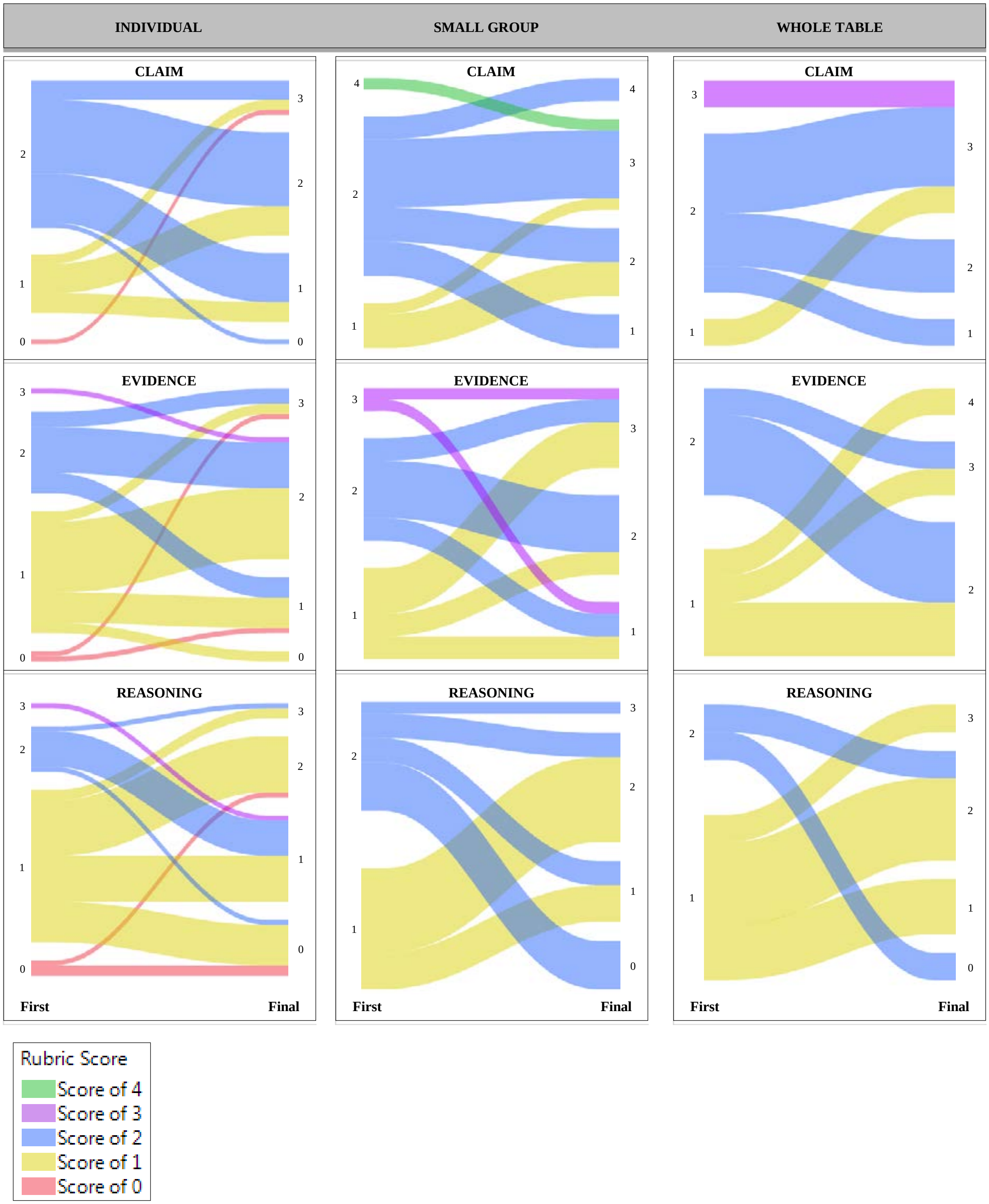

Mean Change in Rubric Score from Individual to Group
MeanΔ Score
2
1
0
-1
First Activity
Final Activity

Figure 2.15: Component rubric score Sankey plots. The Sankey plots represent change over time for each component of the CER activity (Claim, Evidence, Reasoning) at the individual (n = 65), small group (n = 23), and whole table (n = 8) levels of activity. The proportion of students from the total population attaining each rubric score is shown in the flow diagrams, with the first activity on each left y-axis and the final activity on each right y-axis. The color indicated is based on the rubric score given for the first activity.


INDIVIDUAL
SMALL GROUP
WHOLE TABLE
CLAIM
EVIDENCE
REASONING
First
Final
Rubric Score
Score of 4
Score of 3
Score of 2
Score of 1
Score of 0

CHAPTER 3

FLIPPING THE SCIENTIFIC PRACTICE OF CONSTRUCTING EXPLANATIONS IN AN ACTIVE LEARNING PREPARATORY CHEMISTRY COURSE[1]

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[1]Atkinson, M. B.; Krishnan, S.; McNeil, L. A.; Luft, J.A.; and Pienta, N. J. To be submitted to *J. Chem. Educ.*

Abstract

Active learning approaches and methodologies have been shown to increase undergraduate student success, improve attitudes, and reduce misconceptions. Specifically, the flipped classroom approach pushes course content outside of the classroom and thus allows for the focus of each class period to be centered on student-student interactions as opposed to traditional lecture, increasing the ownership of student learning. This flipped approach has been shown to reduce student cognitive load while in the classroom as well as lower the DFW rate in comparison to a standard lecture environment. Although much research has been done on flipping the classroom as an active learning approach, there is little evidence concerning its specific impact in STEM undergraduate courses. To gain insight into how flipping can impact student learning, this design-based research study conducted assessments of students in a non-majors, preparatory chemistry course who engaged in individual and small-group problem solving activities utilizing the claim-evidence-reasoning (CER) framework of constructing explanations. Students completed several CER activities over the course of a semester in which explanations of natural phenomena were constructed, consisting of a claim, evidence that supports the claim, and reasoning describing why the evidence supports the claim. During the first semester of this two-semester study, students in the course completed each CER activity while in class; the second semester of the study students in the same course completed the individual portion of the activity outside of class and exchanged ideas in small groups during the next class period. Results show that shifting the process of individual CER explanation outside of the class allowed for more time that the students spent grappling with the material, leading to more robust and engaging student interactions, better explanations of natural phenomena, and greater chemistry content understanding.

Introduction

Active learning, defined in this study's context as learning through the construction of knowledge by the students themselves during activity, has been shown to increase undergraduate student success, increase conceptual understanding, and improve attitudes (*1;2*). Specifically, the flipped classroom approach contains active learning elements and pushes course content outside of the classroom, allowing for the focus of each class period to be centered on student-student interactions as opposed to traditional lecture (*3-5*). Much of the course content is acquired prior to the student attending class; during class, students can then focus their cognitive thinking on more meaningful learning and applications of that content knowledge attained (*6*). This flipped approach has been shown to promote peer interaction and collaboration skills, make learning instead of teaching central, encourage higher student engagement, provide increased individualized attention, and reduce student cognitive load within the classroom (*7*). In a recent study, students described their preference for the flipped format, specifically when including lecture videos outside of the classroom, because the students felt they could better grasp the material when able to pause and re-watch the videos and control the pace of their own learning (*8*). The flipped format of a course has also been shown to be perceived by students as more "student-oriented", allow students to be more eager to ask questions during class, and make the in-class experience more inviting and intriguing to students (*9-11*). In addition, the professor can focus more on answering student questions and promoting student discussion in the flipped classroom (*11*).

This portion of the research study focuses on the scientific practice of constructing explanations, utilizing the claim-evidence-reasoning (CER) framework developed by Sampson and colleagues from the argument driven inquiry model (*12-15*). An explanation consists of three components: (1) a claim, or a statement or answer to a research question, (2) evidence, or data that has been collected, analyzed, and interpreted in a way that supports the claim, and (3) reasoning, or a statement that explains the importance of the evidence with relevant scientific concepts (*15*). Details of this design framework have been discussed previously in the preceding chapter.

Students must first construct their own individual knowledge, utilizing the theoretical framework of constructivism. Constructivist theory upholds that individuals construct their own knowledge through experience, often through an active learning lens with the focus on the individual student acquiring his or her knowledge and understanding (16). Of particular importance to this study, the students must then place themselves, prepared, in the social context of the classroom in order to co-construct higher knowledge surrounding the concept focused upon within the activity. Social constructivism, a theoretical framework developed by Vygotsky and based on students building content knowledge by interacting with others in knowledge based-settings, plays a crucial role in this study and places high importance on the social learning context of the knowledge construction (*17-19*). Social constructivism involves how social interactions affect the construction of student knowledge and has been shown to aid students in the development of critical thinking skills and conceptual understanding (*20;21*). According to Vygotsky, learning and knowledge construction does not only take place on the individual level, but also on a socially collaborative level through social interaction, making both levels of student interaction (individual and in groups) important (*19*). Productive classroom discourse is vital to this flipped CER model. In fact, the very act of discussing ideas with fellow classmates requires students to construction an explanation of their understanding, fitting well with our design framework (*22;23*).

As demonstrated, flipping the classroom as an active learning approach has been the focus of many research studies. However, there is limited evidence in the literature concerning its impact preparatory chemistry courses, and there is no evidence of its use while students construct scientific explanations. In addition, while the benefits of development of critical thinking and literacy skills are positively impacted by flipping a classroom, it is important to consider that not every classroom can be flipped (*10;24*). This brings into question: can CER activities be “flipped” in a preparatory chemistry course on the university level? To gain insight into how flipping these activities can impact student learning, this portion of the study explored the following research question:

How does flipping the individual construction of explanations outside of an active learning preparatory chemistry classroom impact group development of explanations in the classroom and students’ conceptual chemistry knowledge?

Design

This study is focuses on integrating explanation based activities into an undergraduate preparatory chemistry course (CHEM 1210: Basics of Chemistry) and is part of a larger design-based research project in which a team of five researchers planned, implemented and revised three CER activities that required students to construct explanations involving chemistry phenomena (*25*). For the first iteration of the study, the fall semester of 2017 and discussed at length in the previous chapter, students first completed each activity individually in the classroom, constructing their own individual explanation of the chemistry phenomena. Once completed, students then worked in self-selected small groups of 2-4 students to develop a cohesive small group explanation; during this time, students were encouraged to discuss their claims, evidence utilized, and reasoning components of their individual explanations. Finally, as a whole table of nine students, students developed a whole table explanation.

For the second and flipped iteration of the study (the spring semester of 2018), students in the same course (CHEM 1210) completed the individual portion of the activity outside of the classroom and exchanged ideas in small groups during the next class period. The whole table level of student interaction was deemed too cumbersome in the context of this classroom and course, and thus was not utilized in this second iteration of the study. The levels of interaction for spring 2018 are shown in Figure 3.1.

Participants

This IRB-approved study took place at a doctoral university, designated by Carnegie classification as an institution of highest research activity. The study occurred in a college-level preparatory chemistry course, a 4-credit hour course preceding general chemistry I and specifically created to reduce failure rates. Students entered the preparatory chemistry course either through enrollment in the course prior to the start of the semester or, with an extended drop/add period, enrollment in preparatory chemistry after initially enrolling in general chemistry I. A student-centered active learning environment with upside-down pedagogies (SCALE-UP) classroom was utilized for the course, with each round table holding three computers, moveable chairs, and a large screen nearby that presented activities (*26*). The class format emphasized student-student and student-instructor interactions, with the course containing one instructor and peer-learning assistants. Signature consent for data collection was obtained for a total sample size of 54 participants, including 11 males, 42 females, and one nonbinary participant. This sample of participants is very similar to that used in the previous chapter for the fall semester of 2017.

Data Collection

At the beginning of the spring 2018 semester and prior to the implementation of CER activities in the course, students completed an 11-item demographic questionnaire developed by the research team and administered online and utilized for diagnostic purposes. In addition, participants completed the demographic questionnaire at the close of the semester. The demographic questions were the same questions utilized in the fall 2017 iteration of the study, and can be found in Chapter 2 of this work, Figure 2.1. Questions regarding sex, ethnicity, age, year classification, anticipated major, anticipated grade in the preparatory chemistry course, enrollment in the course, previous chemistry courses taken, interest in chemistry, and group work preference are included in the online survey.

Figure 3.2 shows these demographic categories for all participants (n = 54), both pre- and post-semester. In regard to sex, the population of participants consisted of 78% female, 20% male, and 2% other (nonbinary). In regard to ethnicity, the population was comprised of 72% white, 15% black or African American, 11% Asian, and 2% Native Hawaiian or other Pacific Islanders participants. With respect to age, participants were 28% 18 years old, 52% 19 years old, and 20% between 20 and 25+ years of age. It is noted that this particular question altered slightly in regards to pre- and post-semester, as some students had a birthday that fell within the semester. The post-semester age percentages did not differ greatly, and were as follows: 3% 17 years old, 22% 18 years old, 52% 19 years old, and 26% between 20 and 25+ years of age. The group of participants included 74% freshman, 13% sophomores, 11% juniors, and 2% seniors, relating to student year classification. In addition, 91% of these students had also taken a previous chemistry course, either in college in the previous fall semester of 2017 or through a high school course; 9% of the population had no previous chemistry experience. This was determined to be a representative sample of the CHEM 1210 preparatory chemistry course offered in a typical spring semester, with majority of the student population being 19 years old and in their second semester of undergraduate study.

Figure 3.2 also displays enrollment information for participants in the course. The pie chart shows that 54% of the population initially enrolled in CHEM 1210 (preparatory chemistry), while 41% initially enrolled in CHEM 1211 (general chemistry I) and moved back into CHEM 1210. Of these participants that moved, 13% moved after the first CHEM 1211 exam, while 28% moved before the first CHEM 1211 exam. The remaining 5% of the participants (3 out of the 54 total students in the study) took CHEM 1210 in the previous fall 2017 semester and re-enrolled to take the course again in spring 2018. None of the 3 re-enrolled students were participants in the first iteration of the study.

The majority of students enrolled in CHEM 1210 initially before the start of the semester. This is fairly common in the spring semester, as opposed to the fall semester. Students that enrolled in CHEM 1211 initially and moved into CHEM 1210 before the first CHEM 1211 exam responded with reasoning statements involving their lack of preparation for general chemistry I, and that the course was too fast paced and they felt they needed a stronger chemistry foundation before taking general chemistry I. Some also noted their score on the Chemistry Diagnostic Test (CDT) as reasoning for moving into CHEM 1210. Of those students that noted moving into CHEM 1210 after the first CHEM 1211 exam, most discussed that they did not feel their first exam score was at an adequate level to perform well in the remainder of the general chemistry course. Many in this enrollment category also explained their feeling of a lack of preparation and need for stronger foundational chemistry understanding as the reason for moving into CHEM

1210 after the first CHEM 1211 exam. One student also noted difficulty in taking CHEM 1211 while also co-enrolled in a math course in the same semester.

Three class periods over the course of the spring 2018 semester were selected in which to implement the CER activities, which focused on: (1) gas laws; (2) solubility; and (3) buffers. The in-class, small group portion of each of the activities took place within a 75-minute class period, with the CER activity taking up only 45 minutes of that class time. The first and final CER activities remained constant between the two iterations of the study, fall 2017 and spring 2018, and have been shown previously in Chapter 2 in Figures 2.3 and 2.5. CER Activity 2 was altered slightly between semesters. This second activity was not utilized for analysis in this portion of the study, as the ultimate goal was to show change in explanation ability over time as well as to compare the two semesters in which the study occurred.

Students were administered each of the three activities individually as “homework” assignments; in addition, students were given an online “quiz” administered via Qualtrics that consisted of a five-question multiple choice conceptual pre-test which focused on the chemistry concept associated with the activity (*27*). After each of the in-class portion of each activity, students were given the same multiple choice questions as a post-test measure of conceptual gain. The questions were pulled from the American Association for the Advancement of Science (AAAS) Science Assessment question bank, in which more than 600 items are the result of over a decade of research and test for common science misconceptions among students (*28*). The questions used for each of the three activities remained constant between the two semesters of iteration of the study, with the only difference being in flipping the model of administering the activities. These pre- and post-test questions have been shown previously in Chapter 2 in Figures

2.6, 2.7, and 2.8, with correct answer choices indicated with an asterisk and verified by three expert-level scientists.

Before the first activity, members of the research team came into class at the end of the period and gave a five-minute introduction to the practice of constructing explanations consisting of a claim, evidence, and reasoning. This CER introduction occurred before each activity in the same manner and remained consistent throughout the semester with respect to content delivered (*15;29*). Following CER instruction and for each of the three CER activities, students were directed to where they could find the pre-test questions and the activity on their course website, to be completed as a homework assignment on the individual level of student interaction in this flipped model of CER activities. Students were given a research question and data relating to chemistry phenomena and were asked to develop a claim, support that claim with appropriate evidence from the given data, and provide reasoning connecting the evidence to the claim of the phenomena under study using scientific concepts. Students then brought their own individually constructed explanations into class the next class period and worked in self-selected small groups of 2-4 students to develop a cohesive small group explanation. During this time, students were encouraged to discuss their claims, evidence utilized, and reasoning components of their individual explanations. These two student levels of interaction (individual and small group) can be seen in Figure 3.1. The sample size for each level of interaction is as follows: individual (n = 54) and small group (n = 19). CER components of each constructed explanation from each individual or group interaction level were recorded on the same pencil-and-paper form shown in the previous chapter in Figure 2.10, to be later rubric scored by three members of the research team. Class discourse at the small group level was observed by members of the research team, and the final activity was audio recorded on this small group level of interaction for later studies involving transcription, thematic coding, and qualitative discourse analysis.

Data Analysis

Data from the five-question multiple choice conceptual pre- and post-tests were graded for correctness and studied quantitatively using one-sided paired parametric *t*-tests, as all data satisfied assumptions of normality.

In order to consistently assess each CER participant response form, the CER rubric utilized in the previous chapter was used and can be seen in Figure 2.11. Three members of the research team rubric scored a set of selected response forms in order obtain reliable and consistent scores, ultimately achieving a high degree of inter-rater reliability with high agreement and a Cohen's $\kappa = 0.961$ (Cronbach's $\alpha = 0.982$), $p < 0.005$ (*30;31*). Once a high degree of inter-rater reliability was achieved, the research team independently scored all responses. Each explanation component with a lack of score agreement was reviewed by all three members of the research team included in the scoring process, until complete consensus was reached (*32*). These finalized rubric scores of each explanation component, as well as total rubric score, were analyzed descriptively using Sankey plots, parametric paired *t*-tests, parametric independent *t*-tests, and a 2-way ANOVA.

Results

From the demographics questionnaire, several measures were monitored from pre- to post-semester, as shown in Figure 3.2. Students' anticipated grades in the preparatory chemistry course greatly shifted in the negative direction after the spring semester, and these shifts were similar to those indicated in the fall semester of the study. In the pre-semester questionnaire, 72% of all participants (n = 54) anticipated receiving a final course grade of an A, while 26% of the total population anticipated receiving a letter grade of B and 2% anticipated receiving a letter grade of C. However, the post-semester questionnaire results indicated the following anticipated letter grades for the final preparatory chemistry course grade: grade of A, 19%; grade of B, 42%; grade of C, 33%; and grade of D, 6%. Group work preference results are shown in Figure 3.2. From the pre-semester questionnaire, it was determined that 18% of students preferred to work individually, 65% of students preferred to work in a small group of 2-3 people, and 17% of students preferred to work in a large group of 4-8 people, again very similar to the distributions from the pre-semester results in the previous fall semester. The same post-semester questionnaire resulted in 18% of students preferring to work individually in the course, a majority of 72% preferring to work in small groups of 2-3 people, and 9% preferring to work in large groups of 4-8 people, indicating a shift towards preference of working in small groups over large groups within the classroom.

In regard to student interest in the subject of chemistry, and shown in Figure 3.2, the pre-semester demographics questionnaire revealed that 7% of students were extremely interested, 23% were very interested, 45% were moderately interested, 18% were slightly interested, and 7% were not interested at all. Post-semester shows a shift in interest level, with 4% of students being extremely interested, 12% very interested, 39% moderately interested, 20% slightly interested, and 25% not interested at all. These results are very similar to those indicated from the fall semester, discussed at length in the previous chapter. In comparison to the fall participants, many of the anticipated majors recorded in the spring iteration of the study did not change significantly pre- to post-semester, with 32% and 26% of students anticipating a major of study in biology pre- and post-semester respectively. Indications of anticipated majors in chemistry and engineering remained the same pre- to post-semester at 2% and 6%. Majors which exhibited the most change after one semester were atmospheric science and exercise science, which were 6% and 9% pre-semester and 13% and 13% post-semester, respectively. The remaining percentages are attributed to small numbers of students anticipating majors in the following areas: environmental science, pre-med/dental, pharmaceutical sciences, animal science, pre-vet, mathematics, psychology, and undecided.

With respect to student development of explanation ability, total rubric score distributions (0-12, with 12 being the maximum total score possible) are shown in Figure 3.3 for both the individual and small group levels of student interaction from first to final activity. At the individual participation level, the distribution shown in the histogram appears to obey rules of normality. For the first activity on the individual level (n = 54), the following percentages of each score category were recorded: score of 2 (2%), score of 3 (2%), score of 4 (7%), score of 5 (17%), score of 6 (47%), score of 7 (17%) score of 8 (4%), score of 9 (4%). For the final activity on the individual level (n = 54), the following percentages of each score category were recorded: score of 2 (3%), score of 3 (5%), score of 4 (20%), score of 5 (33%), score of 6 (18%), score of 7 (10%), score of 8 (3%), score of 9 (5%), score of 12 (3%). For clarity, total scores which zero participants achieved have not been indicated in this list, and are represented by 0 % in Figure 3.3. However, at the small group level of interaction, the distributions shown in the histogram appear to have definitive differences from first to final activity. This result was also seen in the previous fall semester at the small group level. In order to assess these differences, paired *t*-test analyses were performed. For the first activity on the small group level (n = 19), the following percentages of each score category were recorded: score of 3 (21%), score of 4 (42%), score of 5 (16%), score of 7 (21%). For the final activity on the small group level (n = 19), the following percentages of each score category were recorded: score of 5 (5%), score of 7 (16%), score of 8 (32%), score of 9 (26%), score of 10 (21%). This represents a huge shift in rubric scores for students when working in small groups versus individually in the flipped CER setting.

The error bar plots for total mean rubric scores at the individual and small group levels of interaction for the first and final CER activity are shown in Figure 3.4, and accompanying paired *t*-test analyses results can be seen in Table 3.1. Both the fall and spring data have been included in Figure 3.4 and Table 3.1 for comparison purposes. For the individual level of interaction, the mean rubric scores for the first activity and final activity differed significantly with a medium effect size for the spring semester in which the CER Activity flipping occurred (M = 0.65, SD = 1.74, $t(54) = 2.27$, $p = 0.03$), but did not differ significantly for the fall semester (M = -0.40, SD = 1.96, $t(65) = 1.51$, $p = 0.14$). For the small group level of interaction, the mean rubric scores for the first activity and final activity differed significantly with a large effect size for the flipped model in the spring semester (M = 1.21, SD = 1.96, $t(19) = 2.69$, $p = 0.02$) but did not differ significantly for the fall semester (M = 0.75, SD = 2.40, $t(23) = 1.40$, $p = 0.18$). These results demonstrate that CER activity rubric scores do not significantly increase over time in the fall semester at the individual or small group levels of interaction; however, rubric scores significantly change over the course of the spring semester with the flipped model of pushing the individual level of explanations outside of the classroom.

In addition, independent *t*-tests were performed in order to assess which activities exhibited significant differences between semesters, as seen in Table 3.2. No significant difference was found in the change in score from individual to small group in the first activity between fall and spring semesters (fall 2017: n = 65, M = 0.20, SD = 1.99; spring 2018: n = 54, M = 0.63, SD = 1.61; $t = 1.49$, $p = 0.14$). However, a significant difference with a medium effect size was shown between semesters with respect to the final activity (fall 2017: n = 65, M = 0.67, SD = 1.38; spring 2018: n = 54, M = 1.45, SD = 1.72; $t = 3.04$, $p = 0.003$).

In order to better compare the total rubric scores at the individual and small group levels of interaction, the change in score was also analyzed, as each small group is composed of 2-4 of those individual students. This change in score (Δ score) represents each student's small group score minus their individual score. The error bar plot for Δ scores for the first and final CER activity is shown in Figure 3.5, with paired *t*-test analysis results shown in Table 3.3. Again, both the fall and spring data have also been included for comparison purposes. The mean Δ scores from first to final activity showed a significant difference with a medium effect size in the flipped version of the CER activities in the spring semester (M = 0.82, SD = 1.91, $t(54) = 2.51$, $p = 0.02$) but did not differ significantly over time for the previous study occurring in the fall semester (M = 0.47, SD = 2.59, $t(65) = 1.13$, $p = 0.27$).

In addition, Sankey plots were again used to visualize student change in explanation ability, with the focus on each claim, evidence, and reasoning piece of the explanations, as well as on both the individual and small group student interaction levels. These Sankey plots are shown in Figure 3.6, and indicate movement over the three discrete CER activities during the course of the spring semester of CHEM 1210 from first to final activity. Again, the proportion of scores from the first activity is the basis for the color indications in the Sankey plot. To illustrate this, when looking at individuals who achieved an evidence score of 3 in the first activity in Figure 3.6, a portion of the individuals improved to develop more accurate claims, with a score of 4 on the final activity. However, in such instances, the axes of the graph make it incorrectly appear that the individuals decreased in score over time. In the Sankey plots, each axis shifts for each activity, as each rubric score on each axis is based on proportion of students attaining that particular score.

When breaking down the total explanation scores into the three components, a general trend can be seen that individuals improve over time after three CER activities in their generation of claims and providing of evidence which accurately supports their claim, and that these improvements are heightened when students work in small groups versus individually. In regard to individual reasoning, the overall findings show that students remain stagnant in their ability to reason why the evidence supports the claim, and these results can be seen even when students work in small groups, similar to overall results attained in the previous fall semester. It is important to highlight specific differences between the fall and spring iteration of the study; this can be seen when comparing Figure 2.15 and Figure 3.6. For the individual portion of the activity, the claim scores for the first activity in the spring semester revealed no students scoring zero, and many more students with scores of 3, when compared with the fall semester. Similarly on the final activity, no students scored 0 on the claim, and there were some students attaining a score of 4. For the individual evidence, there were no scores of 0 on the first or final activity, and more scores of 3 and 4 were observed. With respect to individual reasoning pieces, fewer scores of 0 and more scores of 4 were observed on the first and final activity. When looking at the small group claims, there appears to be no difference between fall and spring semesters. However, when looking at the evidence and reasoning pieces, there are more scores of 2, 3, and 4, and fewer scores of 0 and 1. This indicates that students from the spring semester of the study are beginning their explanation construction at an elevated individual level, and this has a direct impact on their small group explanations in comparison to fall students in the first iteration of the study.

Regarding student conceptual chemistry knowledge, Table 3.4 shows paired *t*-test results of the mean difference from the pre- to post-test concept measures for each of the three CER activities throughout the course of the semester. Data from both the fall and spring semester of the study have been shown; the fall data has been discussed at length in the previous chapter. For CER Activity 1 in the fall semester (n = 56), the pre-test and post-test exhibited the following mean results, respectively: M = 0.56, SD = 0.23; M = 0.62, SD = 0.22; for CER Activity 1 in the spring semester (n = 48), the pre-test and post-test for the fall semester exhibited the following results, respectively: M = 0.54, SD = 0.24; M = 0.63, SD = 0.20. For the CER Activity 3 (n = 46), the pre-test and post-test exhibited the following mean results, respectively: M = 0.32, SD = 0.24; M = 0.37, SD = 0.23; for CER Activity 1 in the spring semester (n = 33), the pre-test and post-test for the fall semester exhibited the following results, respectively: M = 0.35, SD = 0.20; M = 0.42, SD = 0.18. For clarity, the second activity has been removed from analysis, as it cannot be directly compared from fall to spring semesters with the minor changes in the activity itself.

As shown in Table 3.5, the paired samples within semester *t*-test resulted in significant differences from pre- to post-test mean difference in the fall semester for both CER Activity 1 (M = 0.06, SD = 2.24, $t(56) = 2.017$, $p = 0.049$, Cohen's $d = 0.29$) and CER Activity 3 (M = 0.05, SD = 0.14, $t(46) = 2.48$, $p = 0.017$, Cohen's $d = 0.22$). The paired samples within semester *t*-test resulted in significant differences from pre- to post-test mean difference in the spring semester for both CER Activity 1 (M = 0.09, SD = 0.24, $t(48) = 2.60$, $p = 0.012$, Cohen's $d = 0.41$) and CER Activity 3 (M = 0.07, SD = 0.21, $t(33) = 2.04$, $p = 0.05$, Cohen's $d = 0.39$).

Significant differences with small effect sizes within activities for these pre- and post-test scores indicates that students are attaining better scores on those post-test measures in comparison to the pre-test for each activity within both semesters of the study. It is important to highlight that both paired t-tests within semester exhibit small effect sizes; however, the effect sizes in the spring semester are larger with a smaller sample size than those from the fall semester. In order to probe the difference between semesters, an independent t-test was utilized, resulting in data from the first activity ($M = 0.11$, $SD = 0.28$) and the final activity ($M = 0.07$, $SD = 0.18$), shown in Table 3.5, with a t-value of 1.30 and a 95% confidence interval from -0.02 to 0.12. With respect to the mean differences between fall and spring semesters, no significant difference was observed.

Discussion

As noted in the fall semester, students appear to be more realistic about their anticipated course grades and are less interested in chemistry at the end of a semester of preparatory chemistry. In addition, students are also more likely to want to work in small to large group settings, rather than individually, after a semester of preparatory chemistry in which they are interacting in active learning groups. However, this change in group preference is lesser than that observed in the fall semester of the study.

When preparatory chemistry students engage in the scientific practice of constructing explanations, they demonstrate improved conceptual understanding through those pre- and post-test conceptual measures within both the fall and spring semesters of the study. However, with respect to the differences between fall and spring semesters, no significant difference was observed. Students are attaining better scores pre- to post-test in both semesters, and the flipped model utilized in the spring iteration of the study does not necessarily have an effect on that gain in pre- to post-test conceptual score and chemistry concept understanding.

Significant differences were found over time between the first and final activities in the spring semester at both the individual and small group level of student interaction, as well as the change in score from individual to small group interaction. Significant differences were also found between the fall and spring semesters for the final activity. This provides more evidence that the way in which activities are administered to students is important with respect to their change in performance and understanding over time within the course of a semester of preparatory chemistry. In addition, students typically have the most difficulty with the reasoning portion of constructed explanations, and the type of activity has been shown to have a key impact on student construction of the reasoning component of explanations, particularly when working in small groups (*14;33-35*). The marked increase in performance at the small group level of student interaction when compared to the individual level of interaction was seen in the spring semester, as discussed in the previous chapter of the fall semester data. Students from the spring iteration of the study are also beginning their explanation construction at an elevated individual level in comparison to the participants from the fall semester, and this has a direct impact on the development small group explanation.

It remains unclear if a semester effect is present, as these are two very different populations of students. Previous literature has noted a difference in first semester students, who largely feel unprepared for the rigors of university, versus second semester students, who are closer to coming to terms with the reality of the demands of academic life at a university (*36*). Much more work needs to be done in order to assess the true differences between students enrolled in preparatory chemistry in a fall semester versus those students enrolled in a spring semester.

Implications

Specifically designed CER constructing explanations activities may provide students with increased chemistry concept knowledge and better developed explanations of chemistry phenomena at the college preparatory chemistry level in a spring semester. In addition, the way in which these activities are administered to preparatory chemistry students is key with respect to their change in performance and understanding over time. The flipped model of the activities in the spring semester may have had an effect on student development of explanations at both the individual and small group levels of student interaction. Further work must be completed in order to understand how to help fall, first-semester students improve their explanations skills using this flipped model CER approach at both levels of interaction. This spring, second-semester population of preparatory chemistry students must be further explored in order to better understand why their interest levels in chemistry, group work preference, and anticipated course grades change so drastically, and why their anticipated majors of study largely remain constant.

This study also provides more evidence that a small dosage of these flipped CER activities can result in significant change and may provide an effective active learning method. Flipping the individual portion of the CER activities can allow students to come to class with more developed explanations, allowing for more robust conversations and better student-student interactions, producing better explanations of chemistry phenomena. This flip may also allow for better instructor-student interactions. When students take individual time in class to brainstorm their explanation ideas, no in class interactions occur for that portion of time. By pushing the individual explanations outside of the classroom, much more time in class is available for student-student interactions and active instructor-student interactions.

In order for this to be an effective method, it is critical that students come into the classroom prepared with their own individual ideas. If students come to class unprepared, they are relying very heavily upon classmates in the small group discussions, and social constructivism is not benefitting them in their own idea construction. For instructors, incentive for student preparation at the individual level of interaction may be a necessary piece.

A conceptual inventory to measure preparatory student knowledge is still needed for this population of students. Future work should include developing assessment items specific to preparatory chemistry courses, and should contain a much broader sweep of chemistry concepts in order to more accurately reflect gain in conceptual knowledge for these students.

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Table 3.1: Individual and group rubric score mean differences for fall and spring semesters.

	Fall 2017				Spring 2018				
	n	M	SD	*t*	n	M	SD	*t*	Cohen's *d*
Individual Final-First Activity	65	-0.40	1.96	1.51	54	0.65	1.74	2.27*	0.43
Group Final-First Activity	23	0.75	2.40	1.40	19	1.21	1.96	2.69*	0.89

*$p < 0.05$.

Student total rubric score mean differences at the individual (n = 54) and small group (n = 19) levels between the first and final CER activities for both the fall and spring semesters of study. This data was analyzed utilizing paired *t*-tests, with significance levels indicated with an asterisk (*) at the $p < 0.05$ level. Each of the mean differences (M) are indicated, along with sample size (n), standard deviations (SD), *t*-values (*t*), and Cohen's *d*-values (*d*).

Table 3.2: Independent *t*-test comparing individual change in rubric score mean differences between fall and spring semesters.

	First Activity				Final Activity				
	n	M	SD	*t*	n	M	SD	*t*	Hedges' *d*
Fall 2017	65	0.20	1.99	1.49	65	0.67	1.38	3.04*	0.70
Spring 2018	54	0.63	1.61		54	1.45	1.72		

*p < 0.01.

Student mean change in rubric scores (Δ score) differences between the fall and spring semesters within both the first and final CER activities via independent *t*-tests, with change in score being represented by each students' small group score minus their individual score. The sample consisted of 65 participant Δ scores and 54 participant Δ scores for the spring semester, with significance levels indicated with an asterisk (*) at the $p < 0.05$ level. Each of the mean differences (M) are indicated, along with sample size (n), standard deviations (SD), *t*-values (*t*), and Hedges' *d*-values (*d*).

Table 3.3: Individual change in rubric score mean differences for fall and spring semesters.

	Fall 2017				Spring 2018				
	n	M	SD	*t*	n	M	SD	*t*	Cohen's *d*
Final-First Activity	65	0.47	2.59	1.13	54	0.82	1.91	2.51*	0.51

*$p < 0.05$.

Student mean change in rubric scores (Δ score) difference between the first and final CER activities, with change in score being represented by each students' small group score minus their individual score. The sample consisted of 65 participant Δ scores and 54 participant Δ scores for the spring semester, and this data was analyzed utilizing paired *t*-tests, with significance levels indicated with an asterisk (*) at the $p < 0.05$ level. Each of the mean differences (M) are indicated, along with sample size (n), standard deviations (SD), *t*-values (*t*), and Cohen's *d*-values (*d*).

Table 3.4: CER activity pre- and post-test mean differences for fall and spring semesters.

	Fall 2017					Spring 2018				
	n	M	SD	*t*	Cohen's *d*	n	M	SD	*t*	Cohen's *d*
CER Activity 1	56	0.06	0.24	2.01*	0.29	48	0.09	0.24	2.60*	0.41
CER Activity 3	46	0.05	0.14	2.48*	0.22	33	0.07	0.21	2.04*	0.39

*$p < 0.05$.

Paired *t*-test mean difference results comparing CER activity pre- and post-test concept measures, with significance levels at the $p < 0.05$ level and indicated by an asterisk (*). The sample size varied over time throughout the semester, with variations occurring due to student withdrawal and/or decreased motivation to participate in conceptual measures after the activities. Both fall and spring iterations of the study are indicated. Each of the mean differences (M) pre- to post-semester are indicated, along with sample size (n), standard deviations (SD), *t*-values (*t*), and Cohen's *d*-values (*d*).

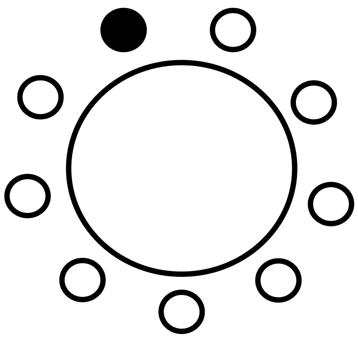
Table 3.5: CER activity pre- and post-test independent *t*-test between fall and spring semesters.

	First Activity		Final Activity			
	M	SD	M	SD	95% CI for Mean Difference	*t*
Spring 2018 - Fall 2017	0.11	0.28	0.07	0.18	-0.02, 0.12	1.30

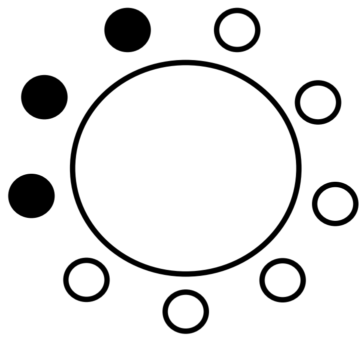
*p < 0.05.

Independent *t*-test results comparing CER activity pre- and post-test concept measures between fall and spring semesters for the first and final activity, with significance levels at the $p < 0.05$ level and indicated by an asterisk (*).Each of the mean differences (M) pre- to post-semester are indicated, along with standard deviations (SD), the 95% confidence interval (95% CI) for mean difference, and *t*-value (*t*).

Figure 3.1: Student levels of interaction during the CER activities, spring 2018. In this flipped CER model, students first constructed an individual explanation for each activity outside of the classroom. Students then brought their own developed ideas into the classroom and worked in self-selected small groups of 3 students to develop a cohesive small group explanation in the classroom. These levels of interaction are indicated at each table in the figure as a solid black circle. For this study, the sample sizes for each level of interaction are as follows: individual (n = 54) and small group (n = 19).



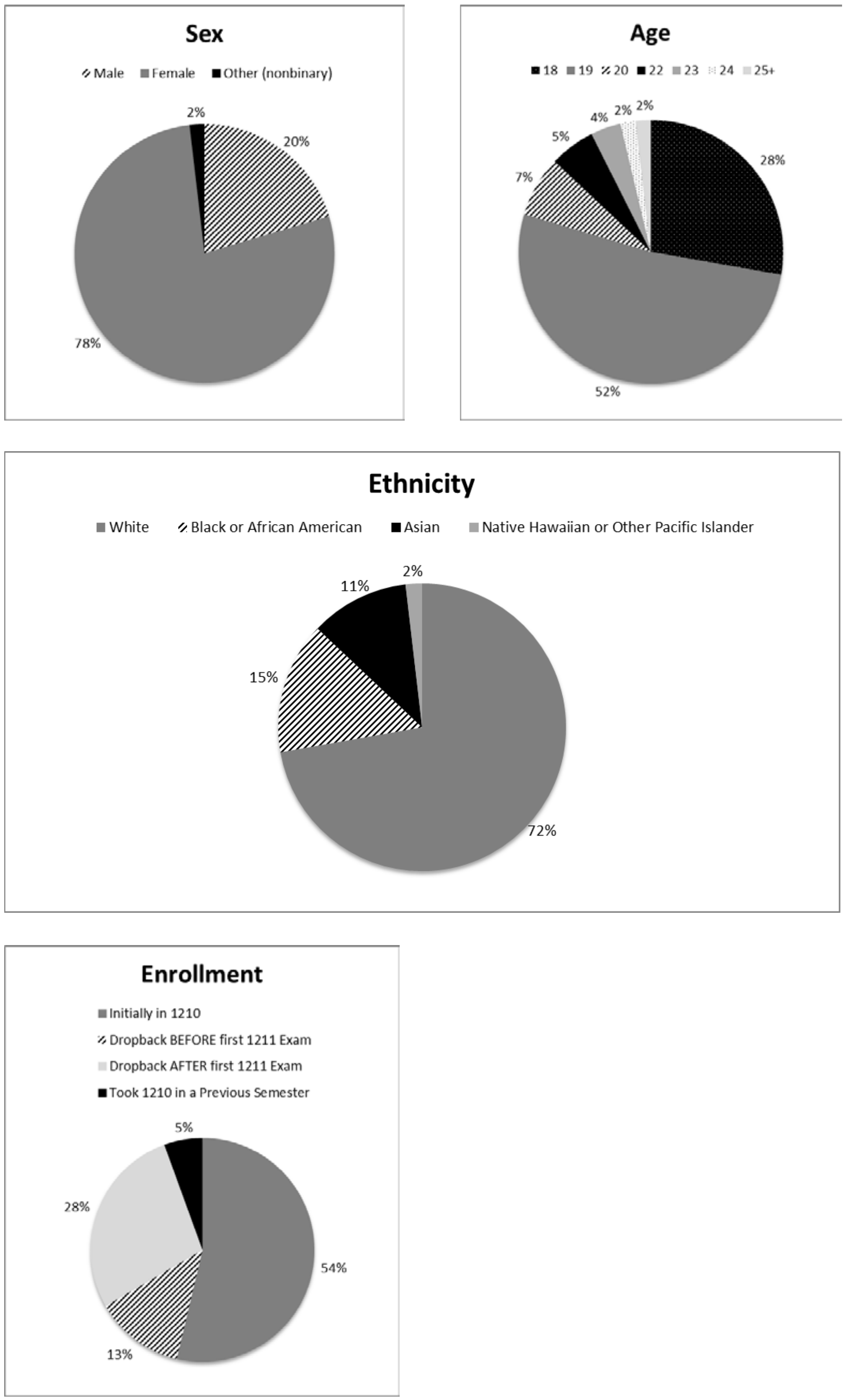
Individual: Outside the Classroom



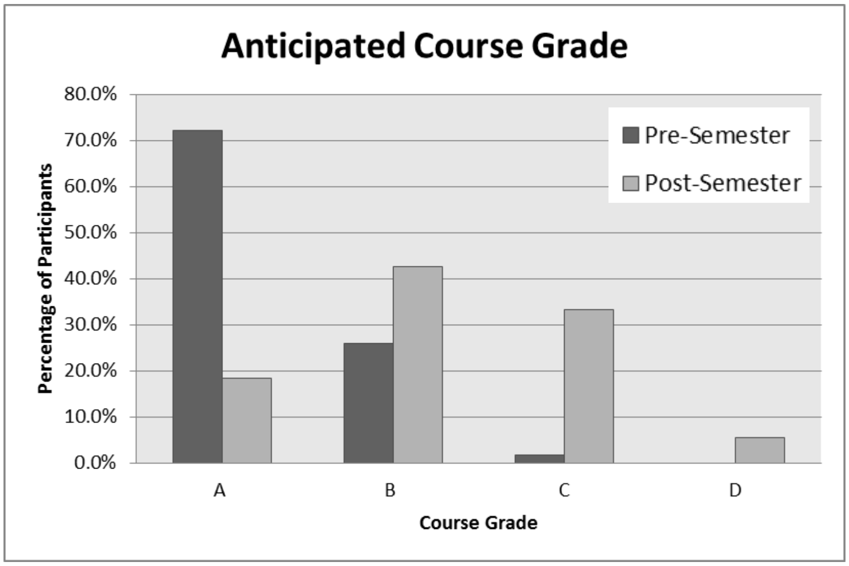
Small Group: Inside the Classroom

Figure 3.2: Demographic questionnaire participant results, spring 2018. (A) Total participant demographics (n = 54) concerning sex, ethnicity, age and enrollment information. Each pie chart is labeled with its own individual legend and percentages of represented categories. These particular survey questions remained consistent from pre- to post-semester, with the exception of age. As the age pie chart was only altered by those students who had a birthday within the semester, only the pre-semester age results have been shown. (B) Survey results for participants' change after one semester of preparatory chemistry for their anticipated course grade, group work preferences, and interest in chemistry from pre- to post-semester, indicated by dark gray and light gray bars, respectively (n = 54).

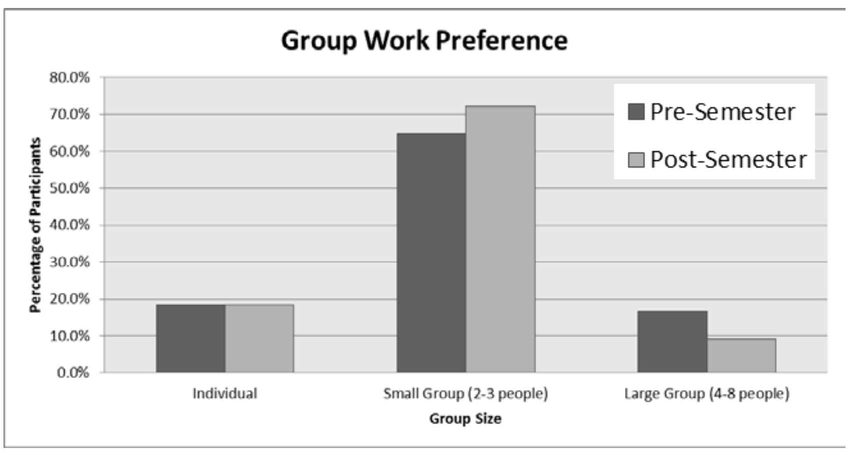
A


Sex
Male
Female
Other (nonbinary)
2%
20%
78%
Age
18
19
20
22
23
24
25+
4%
2%
2%
5%
28%
7%
52%
Ethnicity
White
Black or African American
Asian
Native Hawaiian or Other Pacific Islander
11%
2%
15%
72%
Enrollment
Initially in 1210
Dropback BEFORE first 1211 Exam
Dropback AFTER first 1211 Exam
Took 1210 in a Previous Semester
5%
28%
54%
13%

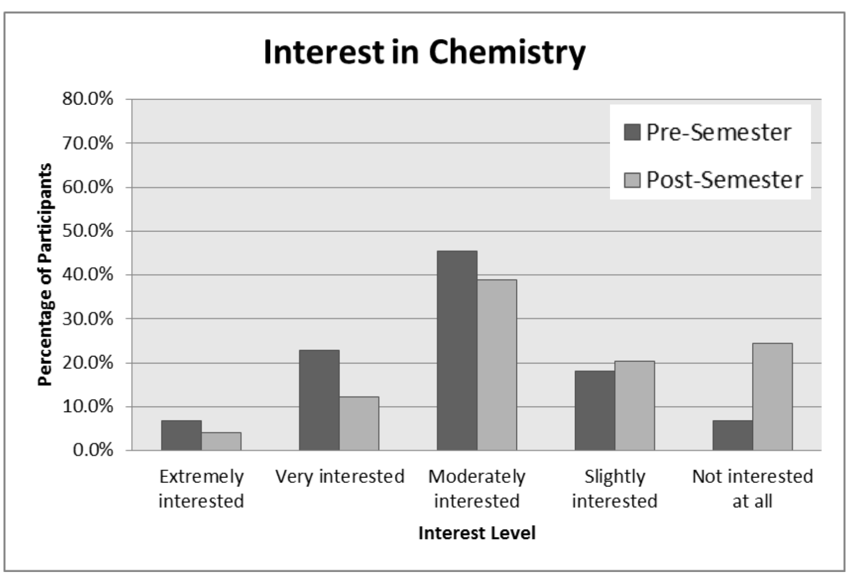
B



Anticipated Course Grade
80.0%
70.0%
60.0%
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
Percentage of Participants
Pre-Semester
Post-Semester
A
B
C
D
Course Grade

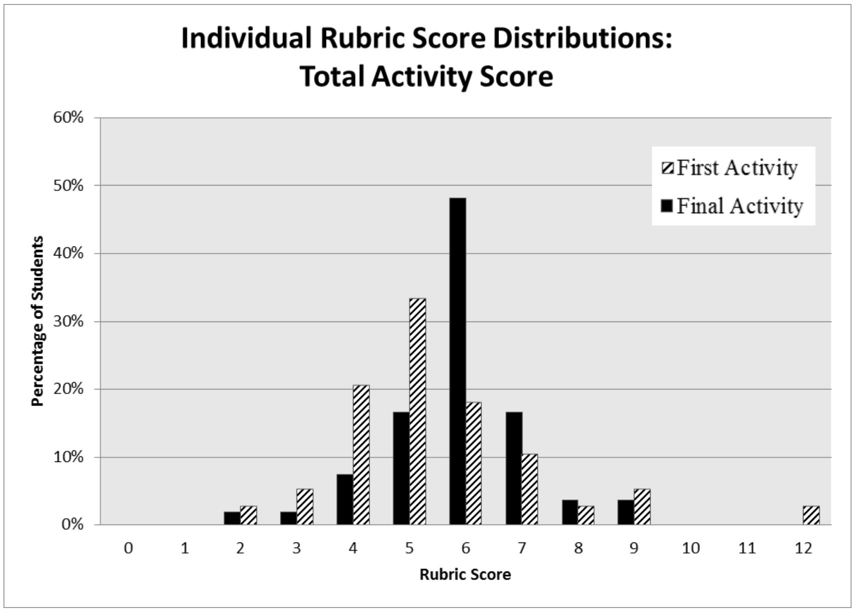


Group Work Preference
80.0%
70.0%
60.0%
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
Percentage of Participants
Pre-Semester
Post-Semester
Individual
Small Group (2-3 people)
Large Group (4-8 people)
Group Size



Interest in Chemistry
80.0%
70.0%
60.0%
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
Percentage of Participants
Pre-Semester
Post-Semester
Extremely interested
Very interested
Moderately interested
Slightly interested
Not interested at all
Interest Level

Figure 3.3: CER activity total rubric score distributions, spring 2018. These distributions are shown for percentage of students attaining each possible total rubric score category (0-12, with 12 being the maximum score possible), from first activity (indicated by the striped bars) to final activity (indicated by the solid bars). Distributions have been included for the individual and small group levels of interaction.


Individual Rubric Score Distributions:
Total Activity Score
Percentage of Students
60%
50%
40%
30%
20%
10%
0%
First Activity
Final Activity
0
1
2
3
4
5
6
7
8
9
10
11
12
Rubric Score

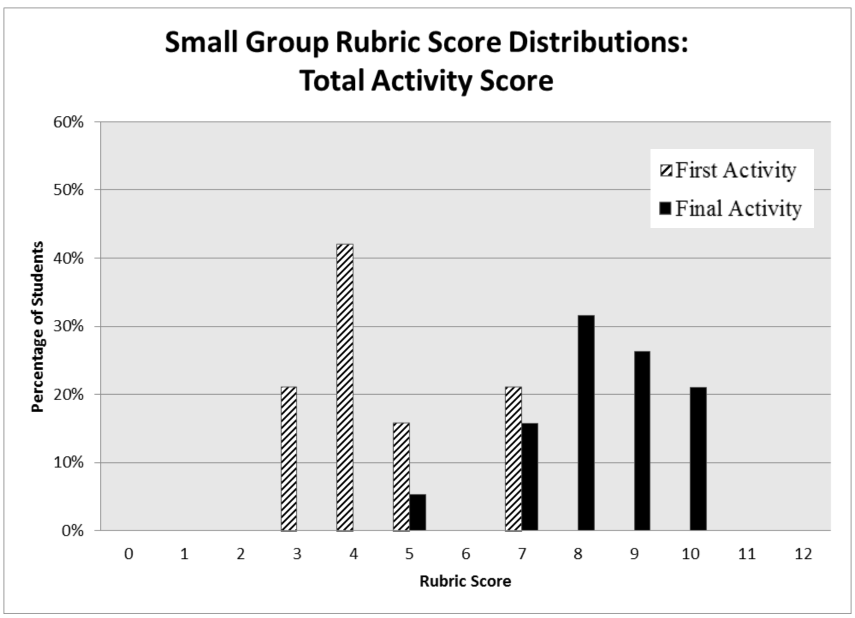
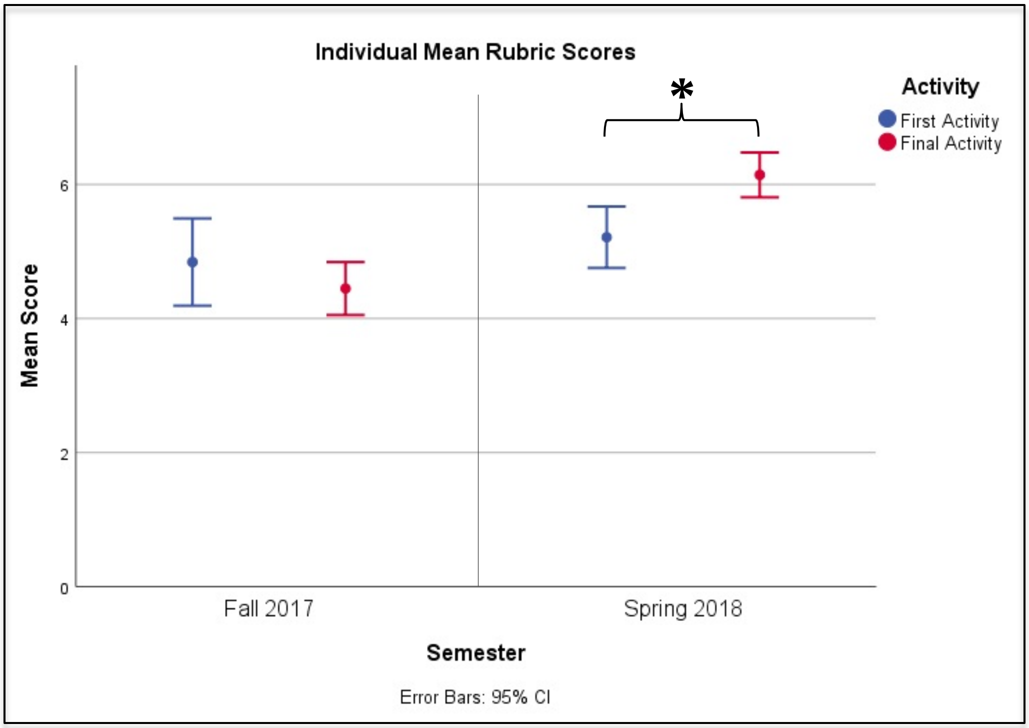

Small Group Rubric Score Distributions:
Total Activity Score
Percentage of Students
60%
50%
40%
30%
20%
10%
0%
First Activity
Final Activity
0
1
2
3
4
5
6
7
8
9
10
11
12
Rubric Score

Figure 3.4: Mean total rubric scores over time, spring 2018. Student mean total rubric scores are indicated at the individual and small group levels of interaction for the first and final CER activities. Both fall and spring iterations of the study are indicated, as well as first activity (shown in blue) and final activity (shown in red), with error bars indicated at the 95% confidence interval. Significance levels are at the $p < 0.05$ level and have been indicated with an asterisk (*).


Individual Mean Rubric Scores
*
Activity
First Activity
Final Activity
Mean Score
6
4
2
0
Fall 2017
Spring 2018
Semester
Error Bars: 95% CI

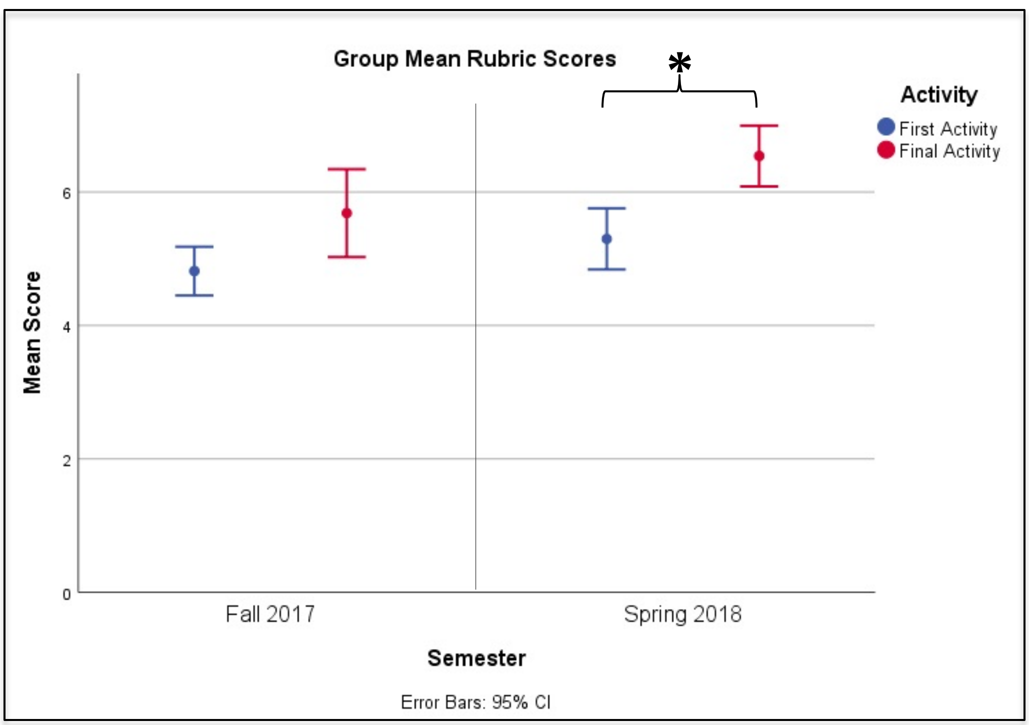
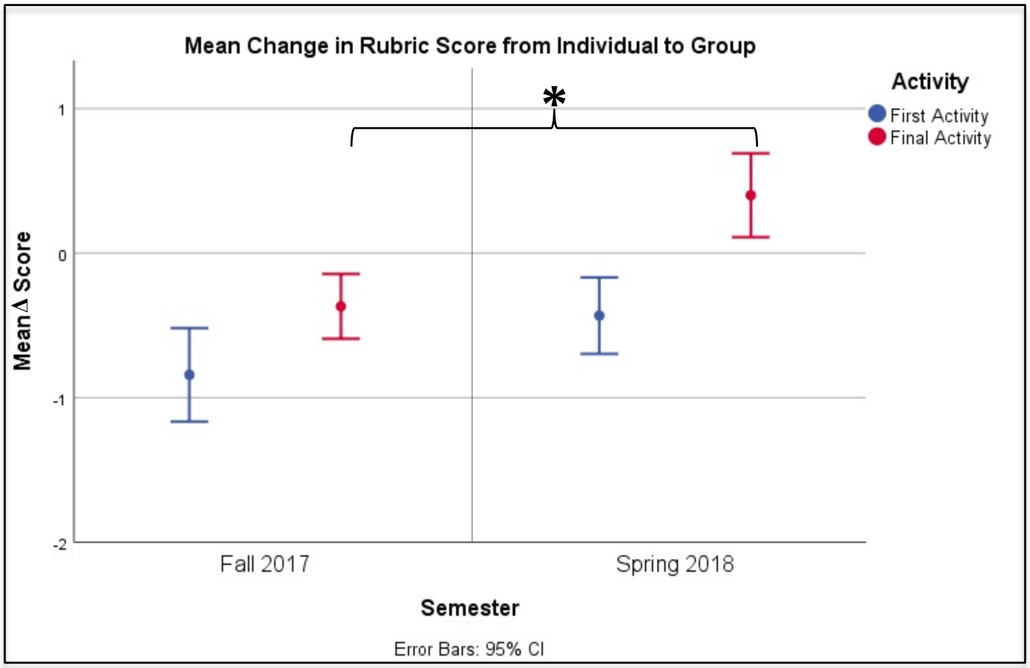
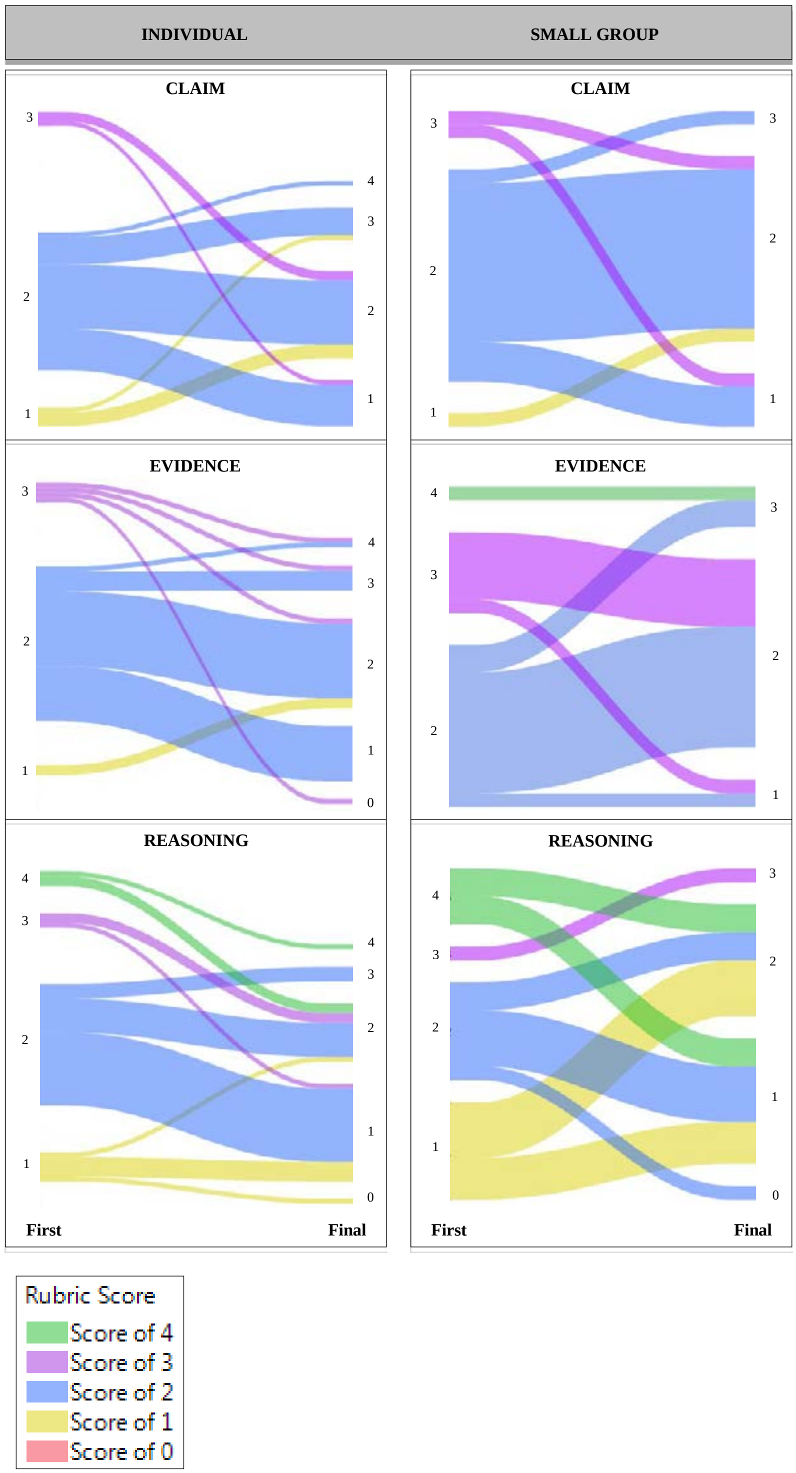

Group Mean Rubric Scores
*
Activity
First Activity
Final Activity
Mean Score
6
4
2
0
Fall 2017
Spring 2018
Semester
Error Bars: 95% CI

Figure 3.5: Change in mean rubric scores, spring 2018. Each student's change in mean total rubric score (Δ score) for the first and final CER activities was analyzed, with the Δ score being represented by each student's small group score minus their individual score. Both fall and spring iterations of the study are indicated, as well as first activity (shown in blue) and final activity (shown in red), with error bars indicated at the 95% confidence interval. Significance levels are at the $p < 0.05$ level and have been indicated with an asterisk (*).



Mean Change in Rubric Score from Individual to Group
Activity
First Activity
Final Activity
*
1
0
-1
-2
Mean Δ Score
Fall 2017
Spring 2018
Semester
Error Bars: 95% CI

Figure 3.6: Component rubric score Sankey plots, spring 2018. The Sankey plots represent change over time for each component of the CER activity (Claim, Evidence, Reasoning) at the individual (n = 54) and small group (n = 19) levels of activity. The proportion of students from the total population attaining each rubric score is shown in the flow diagrams, with the first activity on each left y-axis and the final activity on each right y-axis. The color indicated is based on the rubric score given for the first activity.


INDIVIDUAL
SMALL GROUP
CLAIM
EVIDENCE
REASONING
First
Final
Rubric Score
Score of 4
Score of 3
Score of 2
Score of 1
Score of 0

CHAPTER 4

ATTITUDES AND SELF-CONCEPTS IN AN ACTIVE LEARNING PREPARATORY CHEMISTRY COURSE USING EXPLANATION CONSTRUCTION[1]

[1]Atkinson, M. B. and Pienta, N. J. To be submitted to *J. Chem. Educ.*

Abstract

For undergraduate students, active learning has been shown to result in improved attitudes and increased motivation for future learning. Although a significant amount of research on the success of active learning environments has been completed, there is little evidence concerning how student attitudes towards chemistry and their self-concepts change as they engage in specific activities that promote conceptual understanding in undergraduate general chemistry courses. To gain insight into how attitudes and self-concepts change in an undergraduate active learning preparatory chemistry classroom, this study conducted assessments of students pre- and post-semester who engaged in individual and small-group activities utilizing the claim-evidence-reasoning (CER) framework of constructing explanations over the course of a semester of preparatory chemistry. Analysis revealed that students exhibited a significant shift in improvement of attitudes in the fall semester of the study. No significant differences were found for pre- to post-self-concepts in the fall semester or pre- to post-attitudes and self-concepts in the spring semester of the study. This improvement in only the attitudes may be an effect from the differences in the two populations, as fall semester students are experiencing their first semester as undergraduates, while spring semester students are typically in the second semester of their undergraduate career. This suggests that specific interventions, outside of general active learning, that use explicit approaches may impact other areas aside from content knowledge through social processes. Future directions will explore the shift in attitudes within that fall semester of preparatory chemistry.

Introduction

Approximately half of the population of students in preparatory chemistry (CHEM 1210) at the University of Georgia enroll in the course after initially enrolling in general chemistry I

(CHEM 1210), many of which make this transition due to low performance on the first CHEM 1211 exam of the semester and lack of foundational chemistry knowledge. With that in mind, a majority of the population of students in the preparatory chemistry course began chemistry on the university-level through a less than positive experience. In order to help students improve their attitudes and self-concepts toward the subject of chemistry and turn their preparatory chemistry experiences into something more positive, this study occurred in an active learning environment in which students utilized the scientific practice of constructing explanations using the claim-evidence-reasoning (CER) framework (*1-4*). As discussed previously in Chapters 2 and 3, an explanation consists of three components: (1) a claim, or a statement or answer to a research question, (2) evidence, or data that has been collected, analyzed, and interpreted in a way that supports the claim, and (3) reasoning, or a statement that explains the importance of the evidence with relevant scientific concepts (*4*). The active approach in this preparatory chemistry course using explanation construction allows for the focus of each class period to be centered on student-student and student-teacher interactions as opposed to traditional lecture (*5-7*). In addition, active learning when utilized in a course is often perceived by students as more "student-oriented", allowing them to ask more questions during class without intimidation and creating a more inviting and interesting in-class experience (*8-10*). Specifically, this study explores the following research question:

How are student attitudes and self-concepts impacted after one semester in an active learning undergraduate preparatory chemistry course utilizing explanations activities?

Both attitudes and self-concepts are distinct constructs that are well recognized in the psychology, sociology, and education literature; they are both difficult to observe in the classroom, yet have a huge impact on student learning (*11*). This study primarily utilizes a key component of social cognitive theory as the guiding theoretical framework: self-efficacy, defined as beliefs about ability to perform specific tasks, and affecting student motivation, the ultimate effort students will expend, how long they will persist in the face of obstacles, and task performance and cognitive skill and process development (*12;13*). In addition, self-efficacy has been found to often maintain high correlation with choice of major of study at the undergraduate level, college-level course success, and perseverance (*14;15*).

The two constructs studied in this research project, attitudes and self-concepts, fall under this model of self-efficacy. Attitude is the tendency to react positively or negatively towards a subject, specifically the discipline of chemistry in this study; in particular, a lot of attention has been focused on the relationship between attitude and behavior, and on the issue of how attitudes change (*16;17*). Self-concept is an evaluation of one's ability in a domain, specifically in the domain of chemistry in this study, and self-concept has been identified as a contributing component in conceptual change (*18*). There is much evidence that one's self-efficacy is connected with their domain-specific self-concepts (*19*).

Self-efficacy is influenced by four main sources: mastery experiences, vicarious experiences, verbal persuasion, and emotional and physiological states (*12*). This study focuses on vicarious experiences as a key source that influences self-efficacy, and thus attitudes and self-concepts, through good instruction (*20*). This research aims to engage students and their surrounding peers in vicarious experiences that scientists and chemists practice, such as the construction of scientific explanations, and in doing so, raise student self-efficacy, improve student attitudes and self-concepts, and help students become more aware that they possess the capability to succeed in chemistry tasks and problems.

Design

This study integrates explanation activities into an undergraduate preparatory chemistry course (CHEM 1210: Basics of Chemistry) and is part of a larger design-based research project in which a team of five researchers planned, implemented and revised three CER activities that required students to construct explanations involving chemistry phenomena (*21*). For the first iteration of the study, the fall semester of 2017, students first completed each activity individually in the classroom, constructing their own explanation of the chemistry phenomena. Once completed, students then worked in self-selected small groups of 2-4 students to develop a cohesive small group explanation; during this time, students were encouraged to discuss their claims, evidence utilized, and reasoning components of their individual explanations. Finally, as a whole table of nine students, students developed a whole table explanation. For the second, flipped iteration of the study, the spring semester of 2018, students completed the individual portion of the activity outside of the classroom and exchanged ideas in small groups during the next class period. The levels of interaction for both semesters are shown in Figure 4.1.

Participants

This IRB-approved study took place at a doctoral university, designated by Carnegie classification as an institution of highest research activity, in a university-level preparatory chemistry course. CHEM 1210 is a 4-credit hour course preceding general chemistry I (CHEM 1211), initially developed in order to reduce failure rates. Students entered CHEM 1210 either through enrollment prior to the start of the semester or after initially enrolling in CHEM 1211. An extended drop/add period allows students who initially enroll in CHEM 1211 to make one of three choices early in the semester after their first exam. They can choose to remain in CHEM 1211, withdraw from CHEM 1211 completely, or move into CHEM 1210. The end of this drop/add period begins the start of this research study, in pre- and post-semester attitudes and self-concepts inventories are given (*22;23*). Over the course of each semester in CHEM 1210 in this study, students completed three CER Activities in which explanations of natural phenomena were constructed. This study occurred in a student-centered active learning environment with upside-down pedagogies (SCALE-UP) classroom, with each round table holding three computers, moveable chairs, and a nearby screen that presented activities (*24*). This course emphasized student-student and student-instructor interactions. Signature consent for data collection was obtained for a total sample size in each semester as follows: fall semester, 65 participants comprised of 19 males, 45 females, and one nonbinary participant; spring semester, 54 participants including 11 males, 42 females, and one nonbinary participant.

Data Collection

In order to assess student attitudes and self-concepts, two validated inventories developed by Christopher Bauer were utilized, and paired t-tests were utilized to test for significant differences in mean pre- to post-semester (*22;23*). For the fall semester, a total of 35 participants completed both inventories pre- and post-semester; for the spring semester a total of 45 participants completed both inventories pre- and post-semester. The first inventory used is the Attitudes toward the Subject of Chemistry Inventory (ASCI), which consists of twenty polar adjective pairs, creating a semantic differential on a 7-point Likert scale (*22*). This inventory can be seen in Figure 4.2; students are asked to rank the position between the two opposing words that describes their attitude, or how they feel, about the subject of chemistry. Examples of opposing words include the following: easy or hard, worthless or beneficial, exciting or boring, complicated or simple, confusing or clear. A score of 4 in the middle position of the Likert scale indicates a neutral attitude towards chemistry. This inventory was administered online to students in the form of a Qualtrics survey, both pre- and post-semester (*25*). It is important to recognize that students are given this inventory with some of the adjective pairs listed with the "positive" adjective on the right side of that Likert scale, while some have the "positive" adjective on the left. This helps minimize response bias to insure students are not simply scrolling down the inventory and selecting the first ranking for each pair of adjectives.

The second inventory is the Chemistry Self-Concept Inventory (CSCI), which consists of forty statements on a 7-point Likert scale (*23*). This inventory is shown in Figure 4.3; students are asked to rank how accurately each statement describes them, with 1 indicating a very inaccurate statement, and 7 indicating a very accurate statement. Examples of opposing words include the following:

- "I wish I had more imagination and originality."
- "I find chemistry concepts interesting and challenging."
- "Math makes me feel inadequate."
- "I have trouble with most academic subjects."
- "I enjoy working out new ways of solving problems."

This inventory was also administered online to students pre- and post-semester in the form of a Qualtrics survey (*25*). Again, it is important to note that some of the items are more "positive" statements, while some are more "negative statements". This is a validation measure to help minimize student response bias.

Data Analysis

Regarding the ASCI, the more "negative" of the two opposing words was reversed on the Likert scale for analysis purposes, with a 1 ultimately indicating the left and more "negative" of the two words on the scale and a 7 indicating the right and more "positive" word association. A confirmatory factor analysis was performed, which helps shrink masses of data into a smaller data set in order to better understand hidden and possibly overlapping patterns; a "factor" is a set of observed variables that have similar patterns (*26*, *27*). Each of the twenty items from the attitudes inventory was grouped into five factors. This can be seen in the factor loadings produced by that confirmatory factor analysis, shown in Figure 4.4. The five factors are consistent with the factors found in the literature, and are as follows: interest and utility, anxiety, intellectual accessibility, fear of chemistry, and emotional satisfaction (*22*).

Regarding the CSCI, the more "negative" statements were reversed on the Likert scale for analysis purposes. With this reversal, a 1 ultimately indicated a self-concept of "very inaccurate" towards a positive statement, and a 7 indicated a "very accurate" ranking towards a positive statement. Again, a confirmatory factor analysis was performed, and each of the forty statements from the self-concepts inventory was grouped into five factors. This can be seen in the factor loadings produced by that confirmatory factor analysis, shown in Figure 4.5. The five factors are consistent with the factors found in the literature, and are as follows: math self-concept, chemistry self-concept, academic self-concept, academic enjoyment self-concept, and creativity self-concept (*23*).

Results

With respect to the ASCI, the five factors with their corresponding pairs of adjectives are shown in Figure 4.4. Each item number in the inventory is also shown, and those adjective pairs that were "reversed" for analysis are indicated with an asterisk (*). To highlight examples from each factor, the interest and utility factor contains word pairs such as worthless or beneficial. The anxiety factor contains word pairs such as tense or relaxed. The intellectual accessibility factor contains word pairs such as complicated or simple. The fear of chemistry factor contains the word pairs safe or dangerous. The emotional satisfaction factor contains words pairs such as satisfying or frustrating.

Table 4.1 shows paired *t*-test results for mean differences from pre- to post-semester for each of the five factors in the ASCI, with confidence levels for all data at the $p < 0.05$ level. For all effect sizes indicated in the results, $d > 0.2$ is considered a small effect size, $d > 0.5$ is a medium effect size, and $d > 0.8$ is a large effect size (*28;29*).

During the fall semester of the study, ASCI paired *t*-test results using the mean difference pre- to post-semester show significant differences in mean with large effect sizes in student attitudes for four of the five factors after one semester in preparatory chemistry. These significant shifts occur in the positive direction, with students significantly demonstrating a higher interest in chemistry and an increased attitude towards the utility and usefulness of chemistry (M = 1.55, SD = 2.17, $t(35) = 9.41$, $p = 0.0001$, $d = 1.43$), a feeling that chemistry is more intellectually accessible (M = 0.95, SD = 2.02, $t(35) = 6.20$, $p = 0.0001$, $d = 0.94$), lesser fear of chemistry (M = 2.06, SD = 1.80, $t(35) = 6.77$, $p = 0.0001$, $d = 2.32$), and increased emotional satisfaction towards the subject of chemistry (M = 1.75, SD = 2.22, $t(35) = 2.12$, $p = 0.0001$, $d = 1.59$). However, for the fall semester, results also show that students are significantly more anxious about chemistry and more intimidated by chemistry, with a medium effect size (M = -0.47, SD = 1.26, $t(35) = 4.91$, $p = 0.0001$, $d = 0.74$). This can be seen by the negative mean difference, in that pre- to post-semester, the average mean score significantly shifted lower on that Likert scale and towards the more “negative” adjectives in that factor.

During the spring semester of the study, ASCI paired *t*-test results using the mean difference pre- to post-semester show a significant change with a small effect size in the intellectual accessibility factor (M = -0.21, SD = 1.21, $t(45) = 1.85$, $p = 0.03$, $d = 0.15$), with students significantly demonstrating a feeling that chemistry is less intellectually accessible, again indicated by that negative mean difference. This data can be found in Table 4.1. No significant differences were found for the remaining four attitudes factors in the spring semester, with data as follows: interest and utility (M = 0.01, SD = 1.30, $t(45) = 0.09$, $p = 0.47$); anxiety (M = -0.08, SD = 1.40, $t(45) = 0.66$, $p = 0.75$); fear of chemistry (M = -0.04, SD = 0.95, $t(45) = 0.22$, $p = 0.59$); and emotional satisfaction (M = -0.06, SD = 1.30, $t(45) = 0.42$, $p = 0.66$).

For the CSCI, the five factors with their corresponding statements are shown in Figure 4.5. Each item number in the inventory is also shown, and statements that were "reversed" for analysis are indicated with an asterisk (*). To highlight examples from each factor, the math self-concept factor contains statements such as "I have generally done better in math courses than in other courses". The chemistry self-concept factor contains statements such as "I find chemistry concepts interesting and challenging". The academic self-concept factor contains statements such as "I learn quickly in most academic subjects". The academic enjoyment self-concept factor contains statements such as "I hate most academic subjects". The creativity self-concept factor contains statements such as "I wish I had more imagination and originality".

Table 4.2 shows the results of the paired *t*-tests for mean differences from pre- to post-semester for each of the five factors in the CSCI. Again, confidence levels for all data are at the $p < 0.05$ level. For all effect sizes indicated in the results, $d > 0.2$ is considered a small effect size, $d > 0.5$ is a medium effect size, and $d > 0.8$ is a large effect size (*28;29*).

During the fall semester, CSCI paired *t*-test results of the mean difference pre- to post-semester show a significant change with a medium effect size in the student academic self-concept factor in the "negative" direction, as seen by the negative mean difference (M = -0.47, SD = 1.86, $t(35) = 4.04$, $p = 0.0001$, $d = 0.51$). This demonstrates that the average mean score for this academic self-concept factor significantly shifted lower on that Likert scale and towards the "very inaccurate" side of that statement scale. No significant differences were found for the remaining four self-concept factors in the fall semester, with data as follows: mathematics self-concept (M = 0.07, SD = 2.41, $t(35) = 0.67$, $p = 0.51$); chemistry self-concept (M = 0.05, SD = 1.90, $t(35) = 0.58$, $p = 0.56$); academic enjoyment self-concept (M = -0.06, SD = 2.51, $t(35) =$ 044, $p = 0.66$); and creativity self-concept (M = -0.09, SD = 2.50, $t(35) = 0.46$, $p = 0.65$).

During the spring semester, CSCI paired *t*-test results of the mean difference pre- to post-semester show a significant change with a small effect size in the student chemistry self-concept factor in the "negative" direction, as shown by the negative mean difference (M = -0.18, SD = 1.44, $t(45) = 2.00$, $p = 0.02$, $d = 0.10$). This again demonstrates that the average mean score for this chemistry self-concept factor significantly shifted lower on that Likert scale and towards the "very inaccurate" side of that statement scale. No significant differences were found for the remaining four self-concept factors in the spring semester, with data as follows: mathematics self-concept (M = -0.07, SD = 1.83, $t(45) = 0.81$, $p = 0.79$); academic self-concept (M = -0.07, SD = 1.33, $t(45) = 0.66$, $p = 0.75$); academic enjoyment self-concept (M = 0.08, SD = 1.59, $t(45) = 0.75$, $p = 0.23$); and creativity (M = 0.06, SD = 1.71, $t(45) = 0.46$, $p = 0.32$).

Discussion

Much of this population of preparatory chemistry students began the CHEM 1210 course with a less than positive experience in regard to the subject of chemistry. It is the hope of this research study that through foundational learning in an active learning preparatory chemistry classroom, students would have improved attitudes and self-concepts towards chemistry. Through engaging in the scientific practice of constructing explanations, this study aimed to provide students with vicarious experiences in which to feel like scientists and chemists in the classroom in attempts to improve their attitudes and self-concepts toward the subject of chemistry. In reality, only a partial effect of improvement in attitudes is observed, and only during the fall semester. Students exhibited more positive attitudes toward chemistry, and they feel it is accessible to them in that fall semester. However, they do not have self-concepts of themselves as chemists, and they do not have improved self-concepts of themselves as students. This is not surprising, as it may take much longer to show an effect on self-concepts after only two semesters of their undergraduate career; however, previous literature has shown change in self-concept to be a possible indicator of conceptual change (*30*). More work needs to be completed in order to attempt to promote change in self-concept for students in this population.

The improvement in attitudes may be an effect from the differences in the two populations, as fall semester students are experiencing their first semester as undergraduates, while spring semester students are typically in their second semester of their undergraduate career. It is possible that spring semester student attitudes are somewhat more “fixed” and more difficult to change than fall semester students. These semester differences have not been probed well in the undergraduate preparatory chemistry literature. It is important to assess these potential semester differences; exam scores can tell us some about students, but in order to understand the full picture of the student in a course, more information on their own perceived self-efficacy underlying their attitudes and self-concepts much be attained.

Implications

Enrollment in an active learning preparatory chemistry course using the scientific practice of constructing explanations can have a positive impact on student attitudes for first semester undergraduate students. These findings suggest that specific interventions with explicit approaches occurring within an active learning setting can impact other areas aside from content knowledge through social processes. However, the amount of impact and the semester of activity may be correlated. Much more research needs to be done in order to understand the differences in the fall and spring semester student populations of this course and why this change in attitudes is only seen in the fall semester. This idea of the opening of the door to positive thinking about the subject of chemistry during that first semester may have a huge impact on student experiences in the general chemistry sequence to follow.

A small dosage of explanations activities may be a limitation of this study. It may simply take more activities throughout the course of a semester in order for students to have those vicarious experiences so crucial to their own self-efficacy as chemists and scientists. Also, future studies of this population may be able to make attitude assessments via an abbreviated version which has been validated called the ASCIv2 (*31*). It was important to the researchers to use the full version for the first iterations of the study; however, in the future, the shortened version containing only two of the five original factors may be useful and help minimize student assessment fatigue. In addition, it is also important to note the limitation of utilizing the confirmatory factor analysis, in which you are already limiting your factors to those from the literature. An exploratory factor analysis may provide interesting results for this unique preparatory chemistry population.

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Table 4.1: Attitude toward the Subject of Chemistry Inventory (ASCI) paired *t*-test results.

	Fall 2017 (n = 35)				Spring 2018 (n = 45)			
	M	SD	*t*	*d*	M	SD	*t*	*d*
Interest & Utility	1.55	2.17	9.41**	1.43	0.01	1.30	0.09	
Anxiety	-0.47	1.26	4.91**	0.74	-0.08	1.40	0.66	
Intellectual Accessibility	0.95	2.02	6.20**	0.94	-0.21	1.21	1.85*	0.15
Fear of Chemistry	2.06	1.80	6.77**	2.32	-0.04	0.95	0.22	
Emotional Satisfaction	1.75	2.22	2.12**	1.59	-0.06	1.30	0.42	

*$p < 0.05$; **$p < 0.001$.

Paired *t*-test mean difference ASCI results for fall and spring semesters of study, with significance levels at the $p < 0.05$ level and indicated by an asterisk (*). Each of the mean differences (M) pre- to post-semester of the five attitudes factors are indicated, along with standard deviations (SD), *t*-values (*t*), and Cohen's *d*-values (*d*).

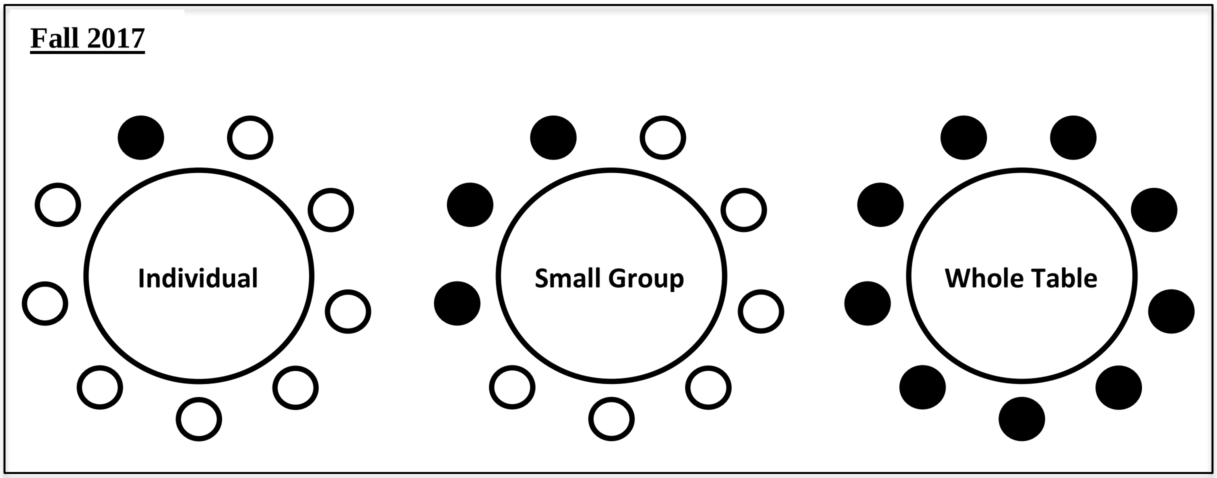
Table 4.2: Chemistry Self-Concept Inventory (CSCI) paired *t*-test results.

	Fall 2017 (n = 35)				Spring 2018 (n = 45)			
	M	SD	*t*	*d*	M	SD	*t*	*d*
Mathematics Self-Concept	0.07	2.41	0.67		-0.07	1.83	0.81	
Chemistry Self-Concept	0.05	1.90	0.58		-0.18	1.44	2.00*	0.10
Academic Self-Concept	-0.47	1.86	4.04**	0.51	-0.07	1.33	0.66	
Academic Enjoyment Self-Concept	-0.06	2.51	0.44		0.08	1.59	0.75	
Creativity Self-Concept	-0.09	2.50	0.46		0.06	1.71	0.46	

*$p < 0.05$; **$p < 0.001$.

Paired *t*-test mean difference CSCI results for fall and spring semesters of study, with significance levels at the $p < 0.05$ level and indicated by an asterisk (*). Each of the mean differences (M) pre- to post-semester of the five self-concept factors are indicated, along with standard deviations (SD), *t*-values (*t*), and Cohen's *d*-values (*d*).

Figure 4.1: Student levels of interaction during the CER activities for fall and spring semester. In the fall semester, students first constructed an individual explanation for each activity, then worked in self-selected small groups of 3 students to develop a cohesive small group explanation, and finally, as a whole table of 9, students developed a whole table explanation. These levels of interaction are indicated at each table in the figure as a solid black circle. For the fall semester of the study, the sample sizes for each level of interaction are as follows: individual (n = 65), small group (n = 23), and whole table (n = 8). In the spring semester using the flipped model, students first constructed an individual explanation for each activity outside of the classroom. Students then brought their own developed ideas into the classroom and worked in self-selected small groups of 3 students to develop a cohesive small group explanation in the classroom. These levels of interaction are indicated at each table in the figure as a solid black circle. For the spring semester of the study, the sample sizes for each level of interaction are as follows: individual (n = 54) and small group (n = 19).


Fall 2017
Individual
Small Group
Whole Table

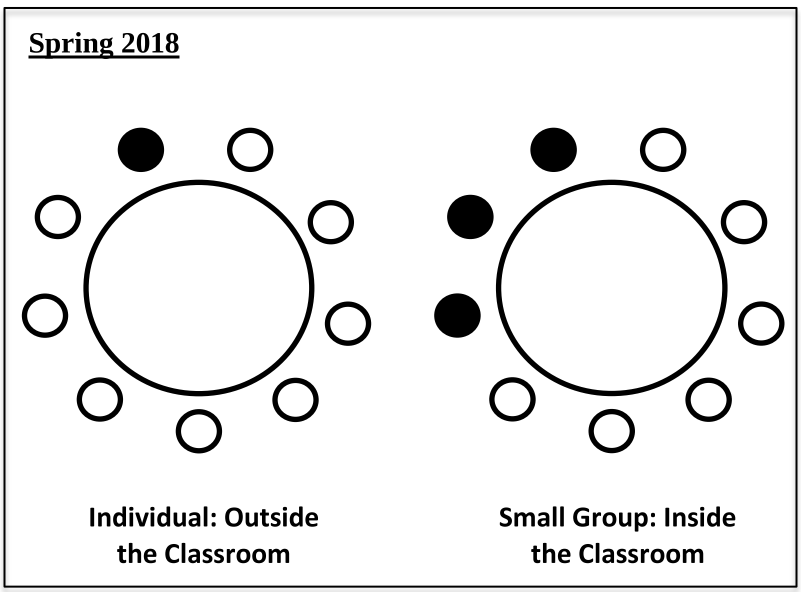

Spring 2018
Individual: Outside the Classroom
Small Group: Inside the Classroom

Figure 4.2: Attitude toward the Subject of Chemistry Inventory (ASCI). The ASCI assesses student attitudes toward chemistry by using a semantic differential; students are asked to rank themselves in terms of attitude about chemistry on a 7-point Likert scale between two polar opposite adjectives (*22*). The items are shown here, exactly as administered to the students.

Chemistry is:

easy	○	○	○	○	○	○	○	hard
worthless	○	○	○	○	○	○	○	beneficial
exciting	○	○	○	○	○	○	○	boring
complicated	○	○	○	○	○	○	○	simple
confusing	○	○	○	○	○	○	○	clear
good	○	○	○	○	○	○	○	bad
satisfying	○	○	○	○	○	○	○	frustrating
scary	○	○	○	○	○	○	○	fun
comprehensible	○	○	○	○	○	○	○	incomprehensible
challenging	○	○	○	○	○	○	○	not challenging
pleasant	○	○	○	○	○	○	○	unpleasant
interesting	○	○	○	○	○	○	○	dull
disgusting	○	○	○	○	○	○	○	attractive
comfortable	○	○	○	○	○	○	○	uncomfortable
worthwhile	○	○	○	○	○	○	○	useless
work	○	○	○	○	○	○	○	play
chaotic	○	○	○	○	○	○	○	organized
safe	○	○	○	○	○	○	○	dangerous
tense	○	○	○	○	○	○	○	relaxed
insecure	○	○	○	○	○	○	○	secure

Figure 4.3: Chemistry Self-Concept Inventory (CSCI). The CSCI assesses student self-concept through 40 statements; students are asked to rank each statement on a 7-point Likert scale between very inaccurate to very accurate (*23*). The items are shown here, including several additional validation measures, exactly as administered to the students.

How accurately does each statement describe you?

	Very Inaccurate	Moderately Inaccurate	Slightly Inaccurate	Neither	Slightly Accurate	Moderately Accurate	Very Accurate
I find many math problems interesting and challenging.	○	○	○	○	○	○	○
I enjoy doing work for most academic subjects.	○	○	○	○	○	○	○
I am never able to think up answers to problems that haven't already been figured out.	○	○	○	○	○	○	○
Validation: Please choose Slightly Accurate.	○	○	○	○	○	○	○
I have never been excited about chemistry.	○	○	○	○	○	○	○
I have hesitated to take courses that involve math.	○	○	○	○	○	○	○
I hate studying many academic subjects.	○	○	○	○	○	○	○
I am good at combining ideas in ways that others have not tried.	○	○	○	○	○	○	○
I participate confidently in discussions with school friends about chemical topics.	○	○	○	○	○	○	○
I have generally done better in math courses than in other courses.	○	○	○	○	○	○	○
I like most academic subjects.	○	○	○	○	○	○	○
I wish I had more imagination and originality.	○	○	○	○	○	○	○
I find chemistry concepts interesting and challenging.	○	○	○	○	○	○	○
Validation: Please choose Moderately Accurate.	○	○	○	○	○	○	○
Math makes me feel inadequate.	○	○	○	○	○	○	○
I have trouble with most academic subjects.	○	○	○	○	○	○	○
I enjoy working out new ways of solving problems	○	○	○	○	○	○	○
When I run into chemical topics in my courses, I always do well on that part.	○	○	○	○	○	○	○
I am quite good at math.	○	○	○	○	○	○	○
I'm good at most academic subjects.	○	○	○	○	○	○	○
I'm not much good at problem solving.	○	○	○	○	○	○	○
I would hesitate to enroll in courses that involve chemistry.	○	○	○	○	○	○	○

How accurately does each statement describe you?

	Very Inaccurate	Moderately Inaccurate	Slightly Inaccurate	Neither	Slightly Accurate	Moderately Accurate	Very Accurate
I have trouble understanding anything based on math.	○	○	○	○	○	○	○
I'm not particularly interested in most academic subjects.	○	○	○	○	○	○	○
I have a lot of intellectual curiosity.	○	○	○	○	○	○	○
I am quite good at dealing with chemical ideas.	○	○	○	○	○	○	○
I have always done well in math classes.	○	○	○	○	○	○	○
I learn quickly in most academic subjects.	○	○	○	○	○	○	○
I am not very original in my ideas, thoughts, and actions.	○	○	○	○	○	○	○
Chemistry intimidates me.	○	○	○	○	○	○	○
I never do well on tests that require math reasoning.	○	○	○	○	○	○	○
I hate most academic subjects.	○	○	○	○	○	○	○
I am an imaginative person.	○	○	○	○	○	○	○
I have always had difficulty understanding arguments that require chemical knowledge.	○	○	○	○	○	○	○
At school, my friends always come to me for help in math.	○	○	○	○	○	○	○
I get good marks in most academic subjects.	○	○	○	○	○	○	○
Validation: Please choose Very Inaccurate.	○	○	○	○	○	○	○
I would have no interest in being an inventor.	○	○	○	○	○	○	○
I have always done better in courses that involve chemistry than in most courses.	○	○	○	○	○	○	○
I have never been very excited about math.	○	○	○	○	○	○	○
I could never achieve academic honors, even if I worked harder.	○	○	○	○	○	○	○
I can often see better ways of doing routine tasks.	○	○	○	○	○	○	○
I have trouble understanding anything based on chemistry.	○	○	○	○	○	○	○

Figure 4.4: ASCI confirmatory factor analysis factor loadings. A confirmatory factor analysis of the ASCI items confirmed five factors, consistent with factors in the literature: Interest & Utility, Anxiety, Intellectual Accessibility, Fear of Chemistry, and Emotional Satisfaction (*22*). This can be seen with the factor loadings, indicating that five factors are confirmed with close association for both semesters of study. The factors and corresponding word pairs are shown, with those items reversed on the scale for further analysis indicated by an asterisk (*). The post-semester results have been shown in this figure, and pre-semester results indicated similar factor loadings.

	Item		Factor Loadings - Fall 2017					Factor Loadings Spring 2018				
	Interest & Utility		**Factor 1**	**Factor 2**	**Factor 3**	**Factor 4**	**Factor 5**	**Factor 1**	**Factor 2**	**Factor 3**	**Factor 4**	**Factor 5**
*	worthwhile	useless	-0.549	-0.457	0.124	0.355	0.441	-0.762	0.210	-0.445	0.220	0.451
	worthless	beneficial	0.716	0.262	-0.009	-0.367	-0.212	0.766	0.112	0.295	-0.278	-0.311
*	good	bad	-0.613	-0.507	-0.001	0.356	0.158	-0.669	0.139	-0.389	0.336	0.126
*	interesting	dull	-0.906	-0.076	0.049	-0.117	0.072	-0.759	-0.040	-0.412	0.283	0.133
*	exciting	boring	-0.805	0.015	-0.014	-0.065	0.379	-0.577	-0.259	0.323	-0.020	0.222
	Anxiety		**Factor 1**	**Factor 2**	**Factor 3**	**Factor 4**	**Factor 5**	**Factor 1**	**Factor 2**	**Factor 3**	**Factor 4**	**Factor 5**
	tense	relaxed	-0.092	0.755	0.184	0.313	-0.151	0.167	0.655	0.482	0.130	-0.023
	work	play	-0.112	0.836	0.057	0.186	-0.155	0.023	0.772	0.253	-0.051	-0.145
	scary	fun	-0.280	0.808	0.088	-0.024	-0.172	-0.065	0.638	0.421	-0.427	-0.265
	insecure	secure	-0.062	0.849	0.242	0.200	-0.059	-0.245	0.796	0.157	-0.001	-0.034
	disgusting	attractive	-0.424	0.531	0.190	0.113	-0.322	-0.533	0.541	0.246	-0.310	-0.377
	Intellectual Accessibility		**Factor 1**	**Factor 2**	**Factor 3**	**Factor 4**	**Factor 5**	**Factor 1**	**Factor 2**	**Factor 3**	**Factor 4**	**Factor 5**
	complicated	simple	-0.002	0.151	0.913	0.208	-0.105	-0.025	0.076	0.861	-0.097	-0.154
	confusing	clear	-0.147	0.334	0.806	0.118	-0.194	-0.081	-0.007	0.775	-0.502	-0.201
*	easy	hard	0.365	-0.286	-0.473	-0.385	0.090	0.205	-0.079	-0.783	0.070	0.017
*	challenging	not challenging	0.087	0.195	-0.747	0.241	0.039	0.014	0.059	-0.819	-0.039	0.077
*	comprehensible	incomprehensible	-0.249	-0.460	-0.637	-0.079	0.244	-0.031	-0.211	-0.763	-0.517	0.238
	Fear of Chemistry		**Factor 1**	**Factor 2**	**Factor 3**	**Factor 4**	**Factor 5**	**Factor 1**	**Factor 2**	**Factor 3**	**Factor 4**	**Factor 5**
*	safe	dangerous	0.101	-0.127	-0.391	-0.761	0.035	0.214	0.018	0.039	0.738	0.089
	Emotional Satisfaction		**Factor 1**	**Factor 2**	**Factor 3**	**Factor 4**	**Factor 5**	**Factor 1**	**Factor 2**	**Factor 3**	**Factor 4**	**Factor 5**
*	pleasant	unpleasant	-0.090	-0.340	-0.375	-0.091	-0.738	-0.509	0.130	-0.116	0.148	-0.680
*	comfortable	uncomfortable	0.316	0.389	-0.360	-0.233	-0.582	0.378	-0.354	-0.022	0.478	-0.488
	chaotic	organized	-0.269	0.238	0.030	0.223	0.747	-0.373	-0.073	0.465	0.475	0.579
*	satisfying	unsatisfying	0.195	-0.493	-0.205	-0.313	-0.546	0.264	-0.485	-0.257	0.279	-0.578

Figure 4.5: CSCI confirmatory factor analysis factor loadings. A confirmatory factor analysis of the CSCI items confirmed five factors, consistent with factors in the literature: Mathematics Self-Concept, Chemistry Self-Concept, Academic Self-Concept, Academic Enjoyment Self-Concept, and Creativity Self-Concept (*23*). This can be seen with the factor loadings from both semesters of study, indicating that five factors are confirmed with close association. The factors and corresponding items are also shown, with those items reversed on the scale for further analysis indicated by an asterisk (*).The post-semester results have been shown in this figure, and pre-semester results indicated similar factor loadings.

Item	Factor Loadings - Fall 2017					Factor Loadings - Spring 2018				
Mathematics Self-Concept	**Factor 1**	**Factor 2**	**Factor 3**	**Factor 4**	**Factor 5**	**Factor 1**	**Factor 2**	**Factor 3**	**Factor 4**	**Factor 5**
17	0.819	0.198	-0.040	-0.176	0.019	0.850	0.279	0.022	0.014	0.146
25	0.723	0.407	0.033	0.082	0.015	0.948	0.071	-0.045	0.020	0.083
* 21	-0.617	-0.111	0.231	0.056	-0.003	-0.805	-0.152	-0.075	0.370	0.134
* 5	-0.775	0.028	-0.035	0.190	-0.082	-0.854	-0.155	0.141	0.182	-0.024
* 13	-0.869	0.043	0.001	0.098	-0.106	-0.825	-0.160	0.075	0.127	0.212
9	0.863	-0.104	0.069	0.163	-0.200	0.794	-0.106	0.137	-0.178	0.141
* 29	-0.455	-0.279	-0.023	0.433	0.113	-0.714	-0.085	0.059	0.513	-0.136
* 37	-0.815	-0.035	0.108	0.274	-0.004	-0.830	-0.165	0.212	0.074	-0.019
33	0.787	0.065	0.067	0.022	-0.098	0.730	0.054	-0.084	0.182	0.419
* 19	-0.557	-0.210	-0.320	0.278	-0.138	-0.599	-0.363	0.122	0.143	-0.179
1	0.827	-0.090	0.031	0.090	-0.039	0.787	-0.058	-0.001	0.073	0.023
Chemistry Self-Concept	**Factor 1**	**Factor 2**	**Factor 3**	**Factor 4**	**Factor 5**	**Factor 1**	**Factor 2**	**Factor 3**	**Factor 4**	**Factor 5**
24	0.318	0.645	0.213	0.246	-0.119	0.081	0.800	0.084	0.344	0.173
* 28	-0.191	-0.736	0.159	-0.121	-0.073	-0.074	-0.662	0.045	0.411	0.034
* 20	-0.009	-0.775	0.340	0.105	0.036	-0.308	-0.797	-0.103	-0.010	-0.014
36	-0.207	0.847	0.047	0.273	0.088	-0.190	0.788	-0.155	-0.085	0.176
16	0.235	0.680	0.084	0.138	-0.126	-0.610	0.560	0.324	0.093	-0.048
* 40	-0.259	-0.536	0.104	-0.144	0.392	-0.302	-0.552	0.437	-0.022	0.021
* 4	0.232	-0.537	0.137	0.356	0.084	0.016	-0.625	-0.478	0.220	0.000
12	-0.142	0.323	0.319	-0.220	0.039	0.042	0.733	-0.344	0.317	0.017
* 32	-0.045	-0.745	-0.058	-0.088	-0.228	-0.105	-0.651	0.446	-0.157	-0.177
8	0.296	0.568	0.258	-0.075	-0.343	-0.063	0.681	-0.319	-0.101	0.059
Academic Self-Concept	**Factor 1**	**Factor 2**	**Factor 3**	**Factor 4**	**Factor 5**	**Factor 1**	**Factor 2**	**Factor 3**	**Factor 4**	**Factor 5**
18	-0.178	0.104	0.762	0.150	-0.169	-0.323	0.283	0.593	-0.359	-0.036
26	-0.160	0.022	0.541	0.191	-0.099	-0.004	-0.409	0.586	0.164	0.157
34	-0.064	-0.068	0.770	0.019	-0.139	-0.230	-0.062	0.703	-0.077	0.469
23	0.040	0.327	0.772	0.222	-0.133	-0.139	0.204	0.715	-0.267	0.287
39	-0.013	0.019	0.475	-0.272	-0.122	-0.061	0.307	0.630	-0.412	-0.153
7	0.097	0.187	0.567	-0.094	-0.298	-0.096	-0.118	0.689	0.258	-0.329
Academic Enjoyment Self-Concept	**Factor 1**	**Factor 2**	**Factor 3**	**Factor 4**	**Factor 5**	**Factor 1**	**Factor 2**	**Factor 3**	**Factor 4**	**Factor 5**
* 30	0.043	-0.454	-0.077	-0.568	0.073	0.021	-0.122	0.029	-0.902	0.099
* 22	0.015	-0.066	0.439	-0.696	0.136	0.142	-0.042	0.102	-0.888	-0.096
* 6	0.433	-0.016	-0.001	-0.547	-0.007	0.435	-0.025	0.208	-0.518	0.108
10	-0.016	-0.047	0.007	0.815	-0.002	-0.118	-0.041	-0.045	0.677	0.302
14	0.317	-0.434	-0.040	0.614	-0.170	0.367	0.051	0.084	-0.731	0.091
2	0.004	0.351	-0.218	0.479	0.356	-0.094	0.170	-0.238	0.758	0.121
* 38	0.141	-0.270	0.040	-0.809	-0.089	0.314	-0.353	-0.168	0.642	-0.140
Creativity Self-Concept	**Factor 1**	**Factor 2**	**Factor 3**	**Factor 4**	**Factor 5**	**Factor 1**	**Factor 2**	**Factor 3**	**Factor 4**	**Factor 5**
* 11	-0.076	0.009	-0.093	0.024	-0.796	0.23	0.01	-0.05	-0.11	0.84
* 27	0.106	-0.045	-0.063	0.518	-0.618	-0.13	0.39	-0.17	-0.05	0.65
31	0.045	0.241	0.224	-0.126	0.683	-0.19	-0.01	0.14	0.43	-0.44
* 35	-0.246	-0.063	-0.426	0.048	-0.524	-0.10	0.01	-0.07	-0.08	-0.77

	Mathematics Self-Concept
17	I am quite good at math.
25	I have always done well in math classes.
21*	I have trouble understanding anything based on math.
5*	I have hesitated to take courses that involve math.
13*	Math makes me feel inadequate.
9	I have generally done better in math courses than in other courses.
29*	I never do well on tests that require math reasoning.
37*	I have never been very excited about math.
33	At school, my friends always come to me for help in math.
19*	I'm not much good at problem solving.
1	I find many math problems interesting and challenging.
	Chemistry Self-Concept
24	I am quite good at dealing with chemical ideas.
28*	Chemistry intimidates me.
20*	I would hesitate to enroll in courses that involve chemistry.
36	I have always done better in courses that involve chemistry than in most courses.
16	When I run into chemical topics in my courses, I always do well on that part.
40*	I have trouble understanding anything based on chemistry.
4*	I have never been excited about chemistry.
12	I find chemistry concepts interesting and challenging.
32*	I have always had difficulty understanding arguments that require chemical knowledge.
8	I participate confidently in discussions with school friends about chemical topics.
	Academic Self-Concept
18	I'm good at most academic subjects.
26	I learn quickly in most academic subjects.
34	I get good marks in most academic subjects.
23	I have a lot of intellectual curiosity.
39	I can often see better ways of doing routine tasks.
7	I am good at combining ideas in ways that others have not tried.
	Academic Enjoyment Self-Concept
30*	I hate most academic subjects.
22*	I'm not particularly interested in most academic subjects.
6*	I hate studying many academic subjects.
10	I like most academic subjects.
14	I have trouble with most academic subjects.
2	I enjoy doing work for most academic subjects.
38*	I could never achieve academic honors, even if I worked harder.
	Creativity Self-Concept
11*	I wish I had more imagination and originality.
27*	I am not very original in my ideas, thoughts, and actions.
31	I am an imaginative person.
35*	I would have no interest in being an inventor.

CHAPTER 5

TRACKING GENERAL CHEMISTRY STUDENT MISCONCEPTIONS THROUGH THE USE OF AN ELECTRONIC LEARNING TOOL[1]

[1]Atkinson, M. B.; Tang, H.; and Pienta, N. J. To be submitted to *J. Chem. Educ.*

Abstract

Most general chemistry students come to class with incorrect or incomplete prior knowledge on the subject of chemistry, and this is often due to the absence of a frame of reference for phenomena that are not directly observable. This study investigates using an electronic learning tool, “Spheres”, to identify and address areas of misconception concerning the particulate nature of matter, as students have been shown to demonstrate a lack of understanding of the meaning of subscripts and coefficients within a chemical reaction. Results indicate that most students do not initially construct correctly balanced molecular drawings without the prompt to balance each reaction, and this is independent of course enrollment. Students also are less likely to obey the Law of Conservation of Mass in their molecular drawings if prompted to alter the number of moles in the reactants and solve for the molar coefficients in the products. In addition, significant differences are observed in the order in which preparatory chemistry and general chemistry students draw reactions on the molecular level.

Introduction

Many undergraduate students come to class with prior knowledge on the subject of chemistry, and many times this prior knowledge is incorrect or incomplete (*1*). This incorrect prior knowledge can be defined as a “misconception”, an understanding or explanation that is different from that of a scientifically accurate and accepted chemistry concept (*2*). The identification of types of student misconceptions has been studied extensively; the National Research Council cites that between the years 2000 and 2010 alone, 120 publications were produced on students’ conceptual understanding of chemistry concepts (*2;3*). These misconceptions, also referred to in the literature as “alternate conceptions”, “prior understandings” or “preconceptions”, must be modified in order for students to build future knowledge upon correct foundational knowledge (*1*).

Chemistry misconceptions are prevalent in many cases due to the absence of a frame of reference for phenomena that are not directly observable; Johnstone’s triangle, as shown in Figure 5.1, illustrates the chemistry triplet of the major constituents of chemistry content, namely symbolic, macroscopic, and particulate or microscopic (*4*). It is crucial that students understand all three domains and are able to appropriately connect symbolic representations to macroscopic and microscopic concepts. Research has shown that students have difficulty with conceptual understanding of all three of these domains; in order to undergo conceptual change, it is important to not only diagnose the specific misconception but also to provide a method through teaching strategies or interactive tools to enable the restructuring of incorrect ideas (*2*).

One of the most important domains of Johnstone’s triangle is the particulate nature of matter, or PNM (*5;6*). Conceptual understanding of the PNM lays the groundwork for understanding a variety of additional chemistry concepts, including chemical reactions, phase changes, equilibrium, and effects of pressure, volume, and temperature on gases (*7;8*). However, it has been shown that students struggle with the concept that matter is continuous, maintaining the misconception that particles are in contact and no empty space exists between them; research has also identified that students sometimes hold the misconception that they can “see” molecules with the naked eye, based upon symbolic images used within textbooks (*9*). Misconceptions that gas particles are static and continuous have also been documented, as well as the misconceptions that matter is not conserved in phase changes, particle spacing within the three phases of matter is the same, particles expand and contract much like the substance they comprise, and attributes of particles, such as color or conductivity, are the same as overall attributes of the substance those particles compose (*9*). Chemistry students have also demonstrated a common misconception involving the lack of understanding of the meaning of subscripts and coefficients within a chemical reaction (*8;10*).

Although much research has been conducted on identifying misconceptions, less has been studied on revising student misconceptions through conceptual change. In order to overcome limitations of assessing student PNM misconceptions via multiple-choice items, several pencil-and-paper drawing assessments have been developed to explore student representations of chemical reactions on the particulate level (*11-14*). While this allows for deeper assessments of large samples of students and their conceptual understanding concerning the PNM, it is still very time consuming to rubric score and quantitatively measure student understanding via pencil-and-paper, open-ended drawing methods (*15*). Interviewing students is another method often utilized to provide insight into student cognitive processes; however, this approach is also very time consuming and requires a large team of researchers (*16*).

An alternative strategy which may be useful in identifying and addressing PNM misconceptions within preparatory and general chemistry at the undergraduate level is the use of electronic learning tools (ELTs), in which learning takes place (either individually or within a group setting) via an electronic or technological component. An ELT has the unique ability to collect large amounts of data very quickly as students are assessed, and with a drag-and-drop drawing feature, the ELT could be used to record student responses and obtain an understanding of student thought processes while drawing chemical reactions on the molecular level. In addition, feedback features can be added to the ELT in order to provide a helpful learning intervention activity for instructors in the course in which it is administered.

This research study aims to design, develop, and administer an ELT to undergraduate preparatory and general chemistry students in order to explore the following two research questions:

1. *How do students represent their understanding of the particulate nature of matter (PNM) across different reaction types in an electronic learning tool (ELT)?*
2. *What strategies are used when looking at reactions on the molecular level within the ELT, and does the order in which the participant draws the reaction impact student understanding?*

Methodology and Design

This IRB-approved research study was conducted in the fall semester of 2016, with the population of study being students enrolled in preparatory chemistry (CHEM 1210, n = 200) and general chemistry I (CHEM 1211, n = 175). "Spheres" is an ELT designed to understand student misconceptions of the particulate nature of matter (PNM) and has been coded and developed, consisting of four chemical reactions. Spheres can be seen in Figure 5.2 and is a browser-based Flash tool in which students can drag-and-drop different atoms represented by "spheres" in order to construct the reaction on the molecular level, while the software records how the students draw each reaction in real time. The ELT takes less than an hour to complete and is distributed to students electronically either during or outside of class. The four reactions are as follows:

Reaction 1	$\underline{\mathbf{2}}NO(g) + O_2(g) \rightarrow \underline{\mathbf{2}}NO_2(g)$
Reaction 2	$CH_4(g) + \underline{\mathbf{2}}O_2(g) \rightarrow CO_2(g) + 2H_2O(l)$
Reaction 3	$Na_3PO_4(s) \rightarrow \underline{\mathbf{3}}Na^+(aq) + PO_4^{3-}(aq)$
Reaction 4	$Mg^{2+}(aq) + 2OH^-(aq) \rightarrow Mg(OH)_2(s)$

It is important to note that the first three reactions are initially given to the students unbalanced, with the initially missing coefficients shown above in bold and underlined text. For the first two reactions in the ELT, participants are prompted through each reaction, with quantitative data being taken through the software for each step. Students are asked to balance the initial reaction and then correct their drawing, construct the reaction with differing amounts of moles of reactants, and identify the limiting reagent for each reaction using the differing amounts of moles of reactants. The specific drawing prompts and questions are listed below, exactly as administered to students, with the submission options in the square brackets following each prompt question:

Initial. Using the tools given, construct how this reaction would look on the molecular level. Drag spheres into drawing areas to represent different atoms. Spheres represent atoms. Atoms in contact with each other represent molecules. Drag an atom out of the work area to delete it. ‘Start’ box for reagents or initial view; ‘Finish’ box for products or outcome. [Submit structure for grading]

Q1. Is the equation for the reaction balanced? [Yes/No]

Q2. Balance the equation by entering the coefficients for each reagent. [Enter coefficients in boxes][Submit]

Q3. Before, did you construct a molecular representation for the *balanced* equation? [Yes/No]

Prompt1. Construct a representation to show how the balanced equation would look on the molecular level. [Submit]

Prompt2. For Reaction 1: Construct how the reaction would look on the molecular level if 4 moles of NO(g) react with 3 moles of O_2(g). Let one molecule equal one mole. [Submit]

For Reaction 2: Construct how the reaction would look on the molecular level if 1 mole of CH_4(g) react with 3 moles of O_2(g). Let one molecule equal one mole. [Submit]

Q4. How many moles of product NO_2 (Reaction 1) or CO_2 (Reaction 2) are produced? [Enter number, Submit]

Q5. Did you have a limiting reagent? [Yes/No]

Q6. What is the limiting reagent? [Type in answer, Submit]

FinalPage. This exercise is now complete.

In contrast, reactions 3 and 4 contain very limited prompts in order to assess student understanding without prompting through the molecular drawing of the reactions. Each prompt for the final two reactions is shown below, with the submission options in the square brackets following each prompt:

Prompt1. Using the tools given, construct how this reaction would look on the molecular level. Drag spheres into drawing areas to represent different atoms. Spheres represent atoms. Atoms in contact with each other represent molecules. Drag an atom out of the work area to delete it. 'Start' box for reagents or initial view; 'Finish' box for products or outcome. [Submit and check]

FinalPage. You have completed this question. Click the 'Start Next Problem' button to continue.

Results

Overall, CHEM 1211 students exhibited higher percent accuracy, though not all significant differences, for questions prompts Q1-Q6 in Reactions 1 and 2, with two exceptions in which CHEM 1210 students achieved higher percent accuracy in Q1 for both reactions and Q6 in Reaction 2. This data can be seen in the error bar plots in Figure 5.3. Preliminary results using paired *t*-tests indicate that a significantly higher percentage of CHEM 1211 students initially constructed a molecular representation for the balanced equation in comparison to CHEM 1210 students for both Reactions 1 and 2, as indicated by percentage correct for Q3. For Reaction 1, CHEM 1211 students also exhibited higher accuracy on correctly identifying the presence of a limiting reagent as well as the identity of the limiting reagent. For Reaction 2, CHEM 1211 students recognized at a significantly higher rate that a limiting reagent was present but identified the correct limiting reagent at a significantly lower percentage than CHEM 1210 students.

Figure 5.4 demonstrates the presence of correct numbers of atoms and molecules, as well as correct ratios of molecules and conservation of mass, in the drawing steps for Reaction 1 in the initial drawing (indicated by red triangles for CHEM 1211 and orange triangles for CHEM 1210), question prompt Q3 (light green squares for CHEM 1211 and dark green squares for CHEM 1210), and question prompt Q4 (light blue circles for CHEM 1211 and dark blue circles for CHEM 1210). As a reminder, Reaction 1 is as follows: $\underline{\mathbf{2}}NO(g) + O_2(g) \rightarrow \underline{\mathbf{2}}NO_2(g)$. Overall, CHEM 1211 students are better able to initially draw the molecular representations of the reactions in comparison to CHEM 1210 students, which is expected. When looking at the reactants, it is clear that initially, most students do not balance the chemical equation. This can be seen by the low percentage correct for the nitrogen atoms, oxygen atoms, and NO(*g*) molecules present on the reactants side of the drawing. However, when looking at the O_2(*g*) molecules present, we see that a large percentage of students, whether in CHEM 1210 or CHEM 1211, draw the appropriate number due to the coefficient for the diatomic oxygen molecule remaining the same in the unbalanced and balanced chemical equation.

Reactions 3 and 4 have no quantitative prompt question data. Strings of this data, as well as data collected with the software from Reactions 1 and 2, containing the molecular representations and ordering information of all of the reactions will be created and analyzed in the future, in order to understand and answer the second research question of this study. Preliminary results of string analysis for Reactions 3 and 4 is shown in Figure 5.5. For Reactions 3 and 4, CHEM 1211 students drew the reactions in a significantly different order than CHEM 1210 students (Rxn3, $p = 0.044$; Rxn4, $p = 0.004$). Much more work needs to be done in order to probe this difference in the order in which students of different populations are drawing reactions on the molecular level.

Examples of common student drawing responses for Reactions 1 are shown in Figure 5.6.

Discussion and Implications

When looking at the quantitative data analyzed for Q3, it is important to realize that most students did not initially construct a balanced drawing for the reaction without the prompt to balance Reactions 1 and 2, whether enrolled in the preparatory chemistry course (CHEM 1210) or the first semester general chemistry course (CHEM 1211), as demonstrated in Figures 5.3 and 5.4.

With respect to Figure 5.4, it is also interesting to note that the correctness of drawing for Reaction 1 largely decreases when the prompt forces students to alter the number of moles of reactants and determine the molar coefficients for the products. Due to this hindrance, students also do not check that their final reaction obeys the Law of Conservation of Mass for this altered chemical equation. It is vital to probe this to determine reasoning behind student choices for drawing these reactions on the molecular level. The presence of atoms and molecules for Reactions 2-4 must also be graphed and compared. It was also determined that the order in which students of different populations are drawing reactions, in particular Reactions 3 and 4, on the molecular level is significantly different. This difference needs to be further studied, both quantitatively and qualitatively. It is important to also understand if this order of drawing has an effect on correctness of drawing.

It is possible that there are CHEM 1211 students in the population of students utilizing the ELT who have taken CHEM 1210 previously. In order to compare those students to CHEM 1211 students who have never taken CHEM 1210, the data must be separated based on those two groups and analyzed separately within the CHEM 1211 data ($n = 175$). That will decrease the sample size significantly, making it vital to continue to conduct this study on a larger scale.

In addition, CHEM 1210 students utilized the Spheres ELT in the middle of the semester (at the end of October of 2016) during the Reactions Unit of the course topics list. In comparison, CHEM 1211 students used the Spheres ELT at the end of the semester (in late November of 2016). In order to make better comparisons of the two different populations, Spheres must be administered in the future: (a) at the same time point in the semester of study, or (b) while both covering reactions as a topic in the course.

Future Work

Much more research must be done in order to attempt to answer the research questions in this study. R-analysis on the order of representation using strings and patterns of strings must be completed for all collected data, including all reactions. In addition, a sample of experts must be obtained to complete the ELT for expert-level comparisons to the population of students.

A major limitation of this study is the tendency of students to simply click through the ELT without putting thought into how they are answering or looking at the problem, resulting in data which does not illustrate students' true cognitive processes when drawing reactions on the molecular level. A possible solution to this problem is to conduct an eye-tracking study, using a T120 Tobii eye tracker and accompanying software, during student use of Spheres on a select population of students in order to better determine students' cognitive processes and conceptual understanding and/or conceptual change throughout the use of this ELT. The sample size of the select population would be assessed utilizing the previous study and g-power calculations. Analysis of this data will include mapping areas of interest, as well as quantitatively analyzing fixation lengths and the order of fixations while using Spheres.

Once analysis of Spheres has been completed on a larger scale, a feedback generation code should also be added to Spheres in order to immediately provide students with right or wrong information as well as feedback and an explanation of the solution. Results from this feedback version of Spheres can be directly compared to the data with no feedback in order to understand the utility of immediate student feedback as an intervention tool when drawing reactions on the molecular level.

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Figure 5.1: Johnstone's Triangle. Johnstone's triangle illustrates the three main domains of chemistry: symbolic, macroscopic, and particulate (microscopic); all three are necessary components for student understanding of chemistry (*4*).

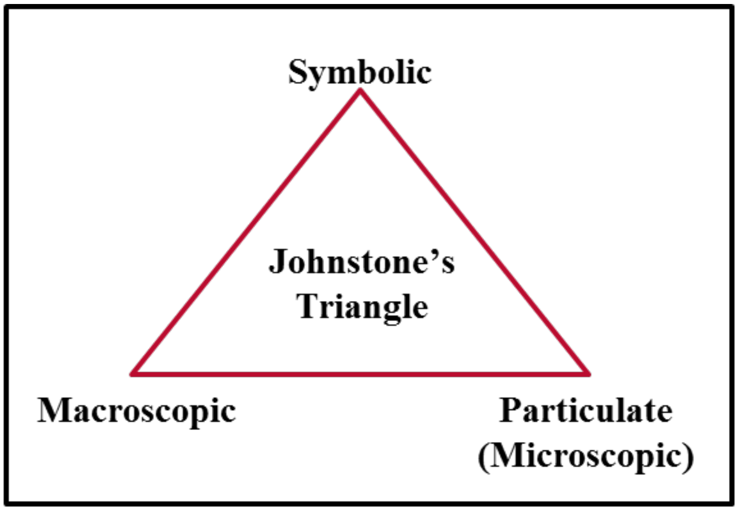
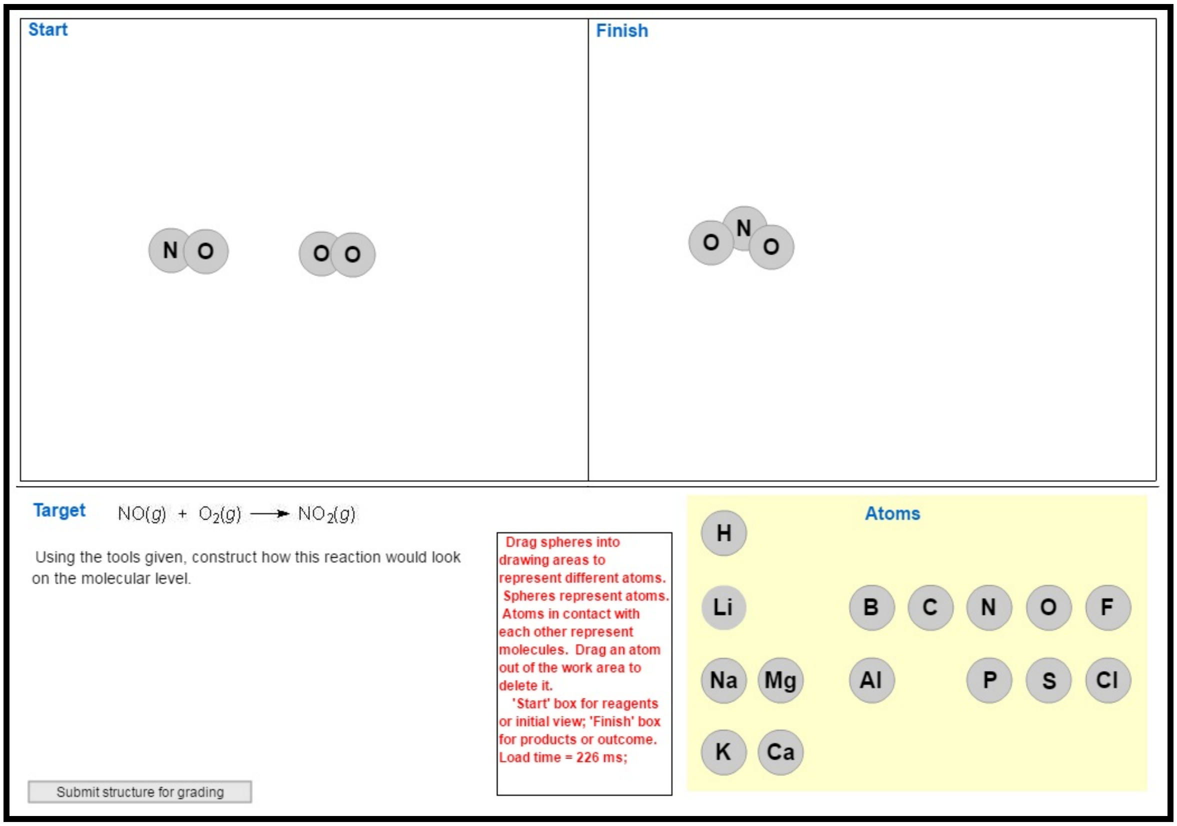
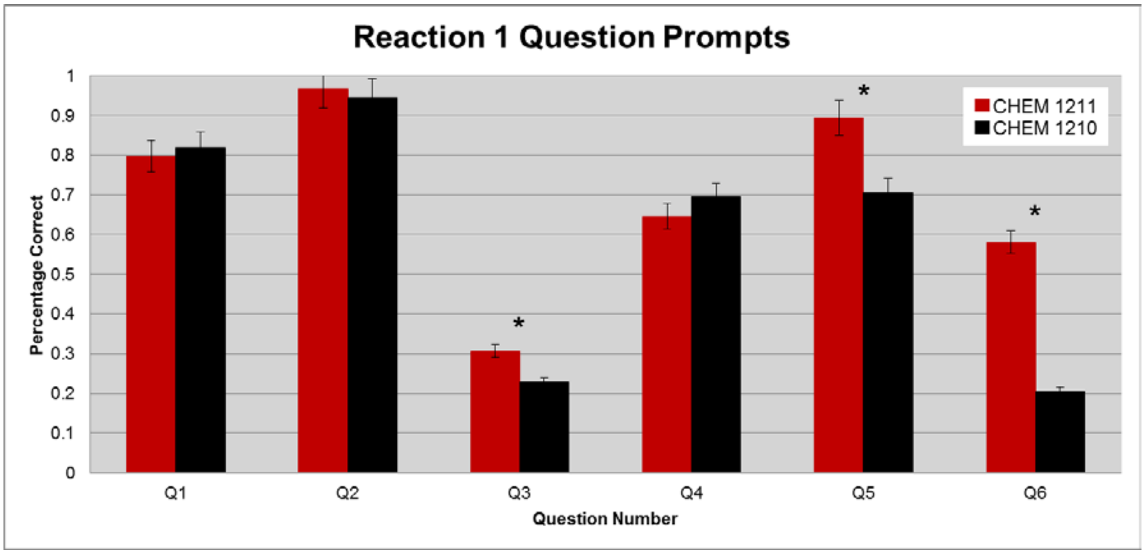

Symbolic
Johnstone's
Triangle
Macroscopic
Particulate
(Microscopic)

Figure 5.2: Spheres, an electronic learning tool. A screenshot of the first reaction with a student response has been shown to illustrate Spheres. Students are able to drag-and-drop the atoms into the start and finish boxes. Prompts, questions, and submission buttons are shown below each reaction. At the bottom of the figure is a sample of the data output recorded in the Spheres software (not seen by students utilizing the ELT). This data shows both the location of atoms dragged into the start and finish boxes of each reaction as well as the order in which they are added, moved, or removed, ultimately leading to the creation of strings of data for analysis.



@1@sph_N_X,42,211,7@2@sph_O_X,72,212,8@3@sph_N_X,32,294,7@4@sph_O_X,66,299,8@5@sph_O_X,228,250,8@6@sph_O_X,256,251,8@7@sph_N_X,767.95,128,7
@8@sph_N_X,768.95,267,7@9@sph_O_X,743.95,292,8@10@sph_O_X,794.95,291,8@11@sph_O_X,791.95,143,8@12@sph_O_X,742.95,148,8@13@sph_N_X,42,113,7@14
@sph_O_X,71,115,8@15@sph_N_X,44,59,7@16@sph_O_X,75,53,8@17@sph_O_X,229,181,8@18@sph_O_X,261,180,8@19@sph_O_X,234,111,8@20@sph_O_X,259,107,8
@21@sph_N_X,595.95,276,7@22@sph_N_X,566.95,125,7@23@sph_O_X,569.95,300,8@24@sph_O_X,618.95,306,8@25@sph_O_X,541.95,146,8@26@sph_O_X,587.95,146
,8@27@sph_O_X,886.95,222,8@28@sph_O_X,919.95,225,8

Figure 5.3: Preliminary Spheres paired *t*-test results. Paired *t*-test results from Reaction 1 and 2 comparing student responses for preparatory chemistry (CHEM 1210, n = 200) and CHEM 1211, n = 175) are shown in the error bar plot of percentage correct for each of the question prompts (Q1-Q6). Significance levels are at the $p < 0.05$ level and have been indicated with an asterisk (*).


Reaction 1 Question Prompts
CHEM 1211
CHEM 1210
Percentage Correct
Question Number
Q1
Q2
Q3
Q4
Q5
Q6
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
*

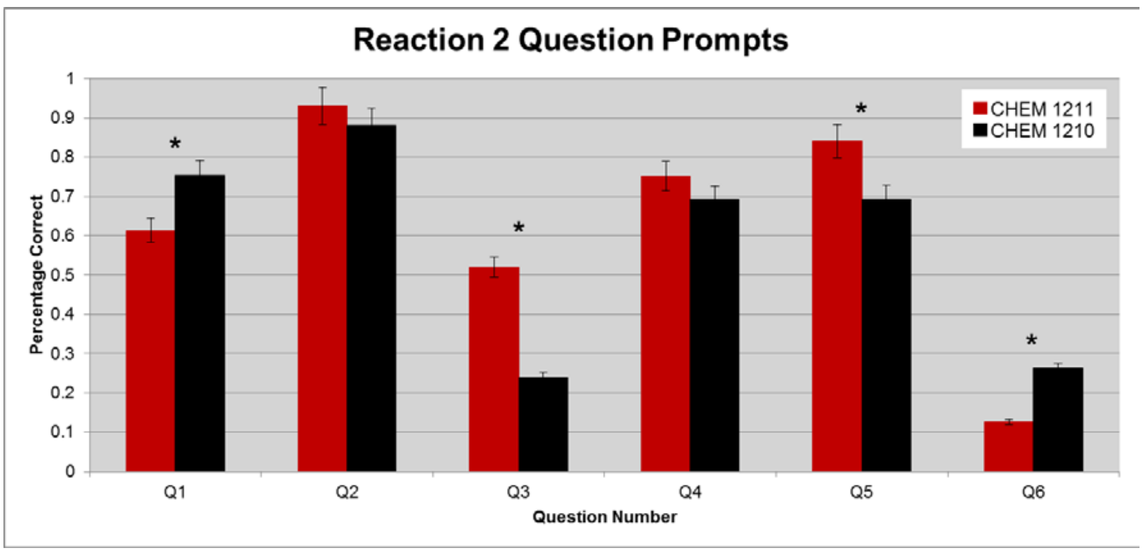
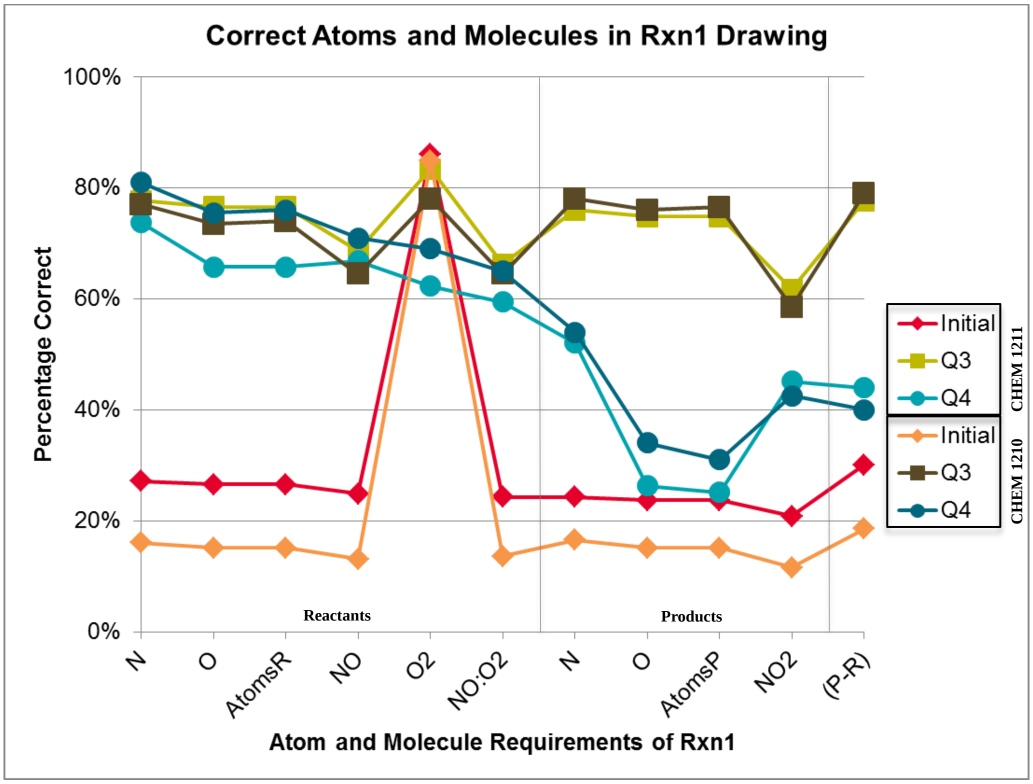

Reaction 2 Question Prompts
CHEM 1211
CHEM 1210
Percentage Correct
Question Number
Q1
Q2
Q3
Q4
Q5
Q6
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
*

Figure 5.4: Presence of correct atoms and molecules in Reaction 1 drawing. This line graph for Reaction 1 shows the presence of correct atoms and molecules in the initial drawing (indicated by red triangles for CHEM 1211 and orange triangles for CHEM 1210), question prompt Q3 (light green squares for CHEM 1211 and dark green squares for CHEM 1210), and question prompt Q4 (light blue circles for CHEM 1211 and dark blue circles for CHEM 1210). As a reminder, Reaction 1 is as follows: **2**NO(*g*) + O_2(*g*) → **2**NO_2(*g*). The step at Q3 asks the students to construct a representation to show how the balanced equation would look on the molecular level, and this graphs assesses that the correct number of atoms and molecules are present in that drawing at that step. The step at Q4 asks the students to construct how the reaction would look on the molecular level if 4 moles of NO(g) react with 3 moles of O_2(g), and this graphs assesses that the correct number of atoms and molecules are present in that drawing at that step. A line separating reactants and products has been inserted on the graph. On the x-axis, the abbreviations are explained as follows:

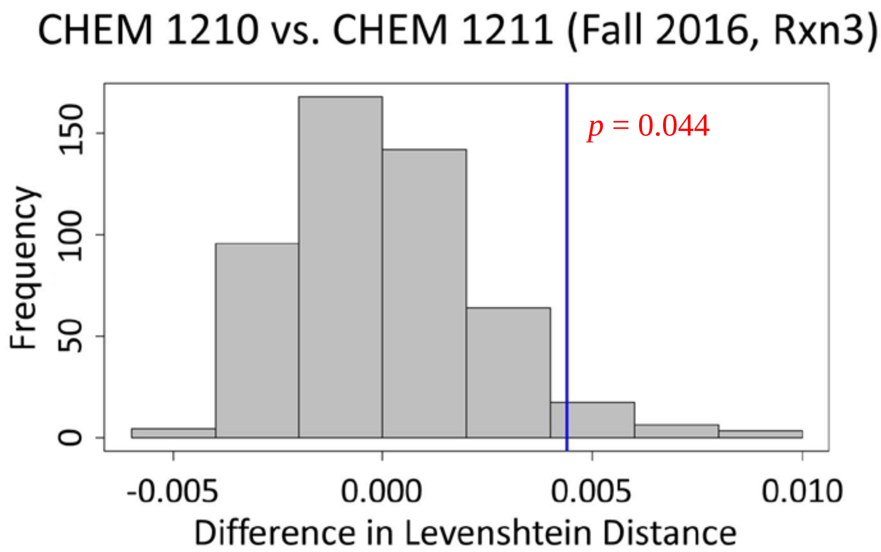
N	Number of nitrogen atoms (reactants and products)
O	Number of oxygen atoms (reactants and products)
AtomsR	Number of atoms in the reactants drawing box
AtomsP	Number of atoms in the products drawing box
NO	Number of NO(*g*) molecules in the reactants
O2	Number of O_2(*g*) molecules in the reactants
NO:O2	Ratio of NO(*g*) to O_2(*g*) molecules in the reactants
NO2	Number of NO_2(*g*) molecules in the products
(P-R)	Number of atoms in the products minus the number of atoms in the reactants (Conservation of Mass)

A line graph has been used to connect the points in order to better see the changes in presence of correct atoms and molecules; keep in mind that the data points are not continuous or connected. They are discrete data points, connected only for ease of viewing.



Correct Atoms and Molecules in Rxn1 Drawing
100%
80%
60%
40%
20%
0%
Percentage Correct
Reactants
Products
N
O
AtomsR
NO
O2
NO:O2
N
O
AtomsP
NO2
(P-R)
Atom and Molecule Requirements of Rxn1
Initial
Q3
Q4
CHEM 1211
Initial
Q3
Q4
CHEM 1210

Figure 5.5: Preliminary Spheres strings analysis for Reactions 3 and 4. Strings of the drawing data from the Spheres software were created to probe whether patterns emerged, utilizing the R package GrpString, developed for the analysis and comparison of strings using Levenshtein distances (LDs) between different groups of strings of data (*17*). When comparing two groups of strings statistically, the null hypothesis (H0) is that the average normalized between-group LD is equal to the average normalized within-group LD. Under this null hypothesis, the difference between the two average normalized LDs should be zero. The strings represent the order in which a student dragged each atom into the reactants and products boxes. The histograms for the comparison of CHEM 1210 and CHEM 1211 strings of data for Reactions 3 and 4 are shown. As a reminder, Reaction 3 is as follows: $Na_3PO_4(s) \rightarrow \underline{\mathbf{3}}Na^{+}(aq) + PO_4^{3-}(aq)$. Reaction 4 is as follows: $Mg^{2+}(aq) + 2OH^{-}(aq) \rightarrow Mg(OH)_2(s)$. Students were simply asked to draw the reaction with minimal prompts. Each histogram represents the distribution of the differences in the average LD, and the observed difference from the normalized distribution is marked by the blue line. Significance levels are at the $p < 0.05$ level, with the p-value indicated in red text.


CHEM 1210 vs. CHEM 1211 (Fall 2016, Rxn3)
p = 0.044
Frequency
0
50
100
150
-0.005
0.000
0.005
0.010
Difference in Levenshtein Distance

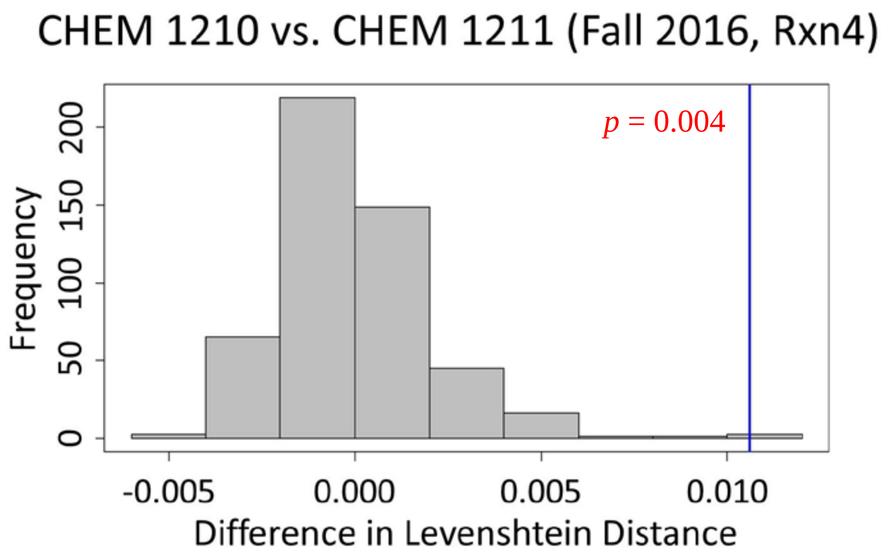
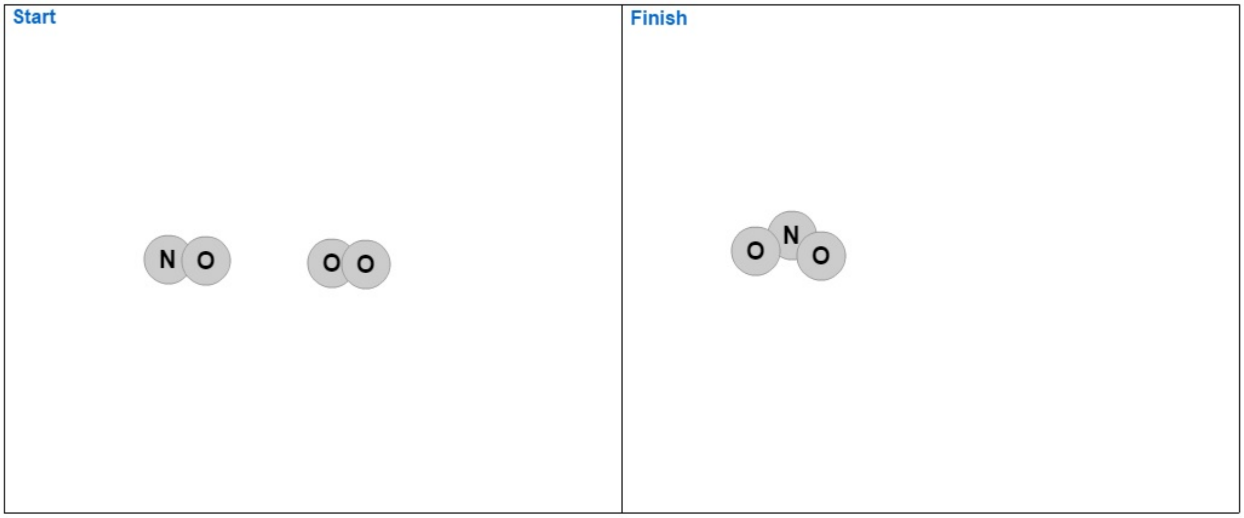
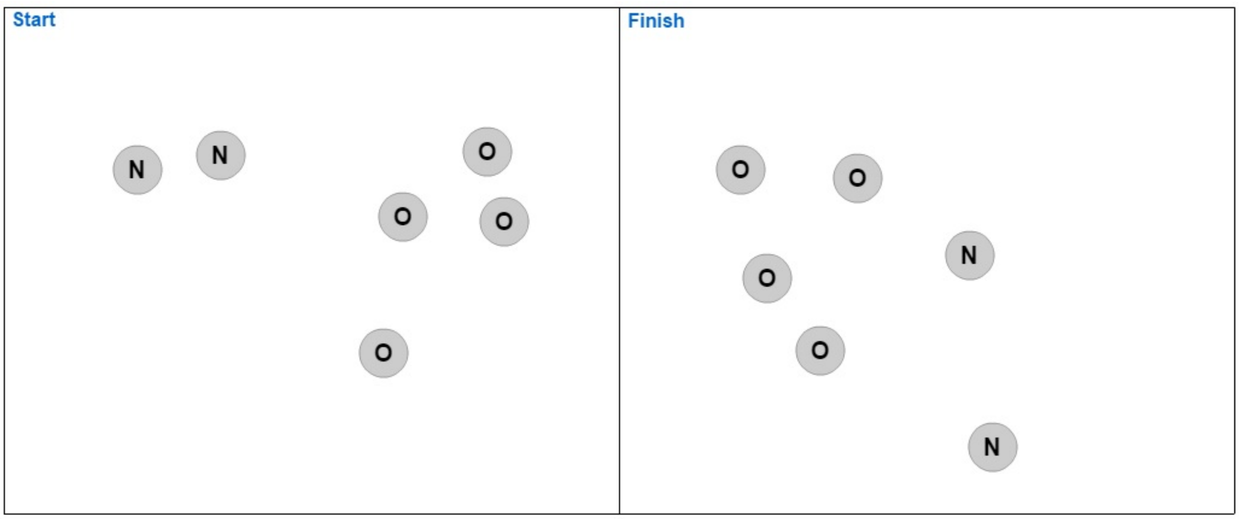
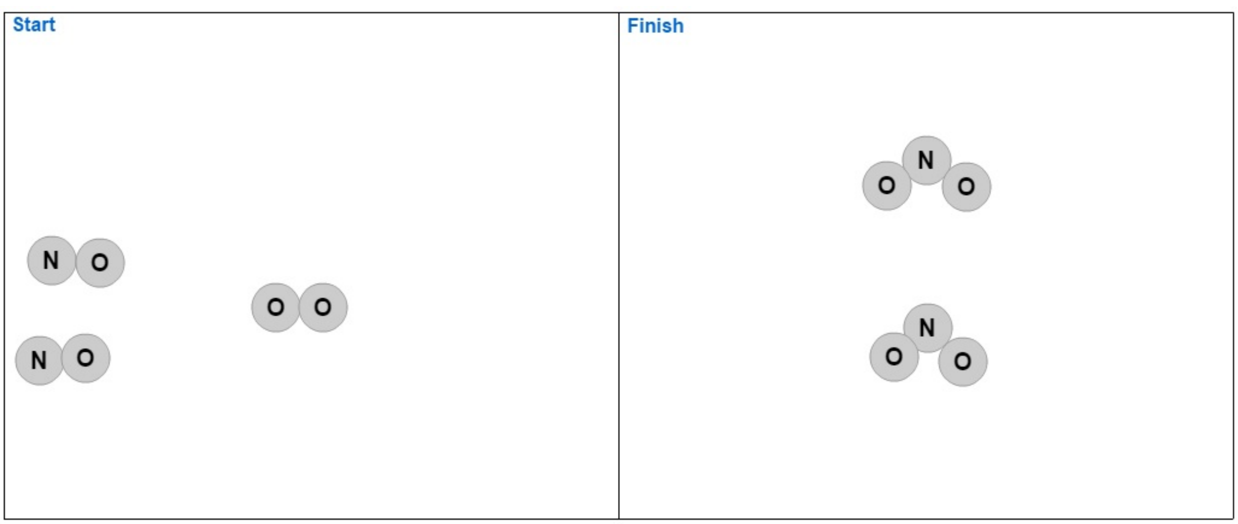

CHEM 1210 vs. CHEM 1211 (Fall 2016, Rxn4)
p = 0.004
Frequency
0
50
100
150
200
-0.005
0.000
0.005
0.010
Difference in Levenshtein Distance

Figure 5.6: Examples of student responses for Reactions 1. Examples of common student responses for the initial drawing of Reaction 1 on the molecular level are shown. As we can see in the first example, most students completed the drawing initial exactly as the reaction was given to them without first balancing the equation. The second example indicates another common response in which students do not connect the atoms appropriately in order to create molecules, as instructed. The third example shows an appropriate student drawing response for the initial drawing of Reaction 1.


Start
Finish


Start
Finish


Start
Finish

CHAPTER 6

CONCLUSIONS AND FUTURE DIRECTIONS

Objectives

The overall objectives of this work were to explore student learning and affective characteristics in a preparatory chemistry course, a course which precedes first semester general chemistry, while constructing explanations in individual and small group settings using the claim-evidence-reasoning (CER) framework. Overall results indicate that by shifting the process of individual CER explanation construction outside of the classroom, more in-class time is available for student-student interactions, leading to greater student engagement, greater chemistry content understanding, and overall better explanations of natural scientific phenomena.

Major Contributions

The research studies contained in this dissertation build on the limited prior work involving explanation construction in the undergraduate chemistry classroom, specifically in a preparatory chemistry student population.

The first major contribution of this work is the knowledge that a small dosage of constructing explanations activities can provide students with increased concept knowledge and better developed explanations of chemistry phenomena at the undergraduate preparatory chemistry level, and that student development of those explanations is heightened through the use of a flipped classroom approach (*1-3*). The way in which activities are administered to preparatory chemistry students is important with respect to their change in performance and understanding over time (*4;5-7*). Flipping the individual portion of the activities may allow students to come to class with more developed individual explanations, leading to better student-

student interactions in the classroom through conversations containing higher-order thinking (*8*). The flip of these activities may also allow for much more active instructor-student interactions; instead of teaching the students content knowledge, through the flip of these activities, students are now applying that content knowledge attained outside of the classroom to activities while in class (*9*). This allows for the instructor to circulate the room and aid students in the discussion of applied knowledge, creating more robust conversation concerning chemistry phenomena (*10*). As discussed in Chapter 3 of this work, it is imperative that students come into the classroom prepared with their own individual ideas and explanations for the activities. Without adequate preparation on the individual level of interaction, students cannot actively and fully participate in the small group discussions in class.

The second major contribution of this work is that enrollment in an active learning preparatory chemistry course using this scientific practice of constructing explanations can have a positive impact on student attitudes for first semester undergraduate students, proposing that specific, well-developed interventions in an active learning, discussion-based social setting can impact affective characteristics of students in addition to their knowledge of the academic content. However, this research also suggests the likelihood that this impact is affected by the semester in which the student is enrolled in the course; more studies must be executed to understand the semester differences in student populations of this course between the fall and spring, and why an improvement in attitudes is only seen in the fall semester (*11*). The improvement in student attitudes with respect to the subject of chemistry is important, as student thinking towards the subject of chemistry during their first semester may have a huge impact on student experiences in the rigorous general chemistry sequence to follow (*12;13*).

The third major contribution of this work is that, when asked to draw chemical reactions on the molecular level, many students do not initially balance the reaction before constructing the drawing (*14-16*). This result does not seem to be impacted by enrollment in a particular course, between preparatory chemistry and first semester general chemistry. In addition, correctness of the drawing of chemical reactions is greatly impacted when prompting students to alter the number of moles of reactants and determine the molar coefficients for the products of the reaction; students have also been shown in these preliminary research findings to draw reactions that do not obey the Law of Conservation of Mass (*15*). It was also determined that the order in which students of different populations draw chemical reactions on the molecular level is significantly different between preparatory and general chemistry.

Future Research

In regard to future work, the fall semester is comprised of a much larger sample size of preparatory chemistry students, and thus, more research must be completed in order to test the flipped model within a fall semester in order to test these results of improvement of student explanations. Further studies of this population of preparatory chemistry students must also be conducted in order to better understand why their interest levels in chemistry, group work preference, and anticipated course grades change so drastically; in addition, it is also important to assess why fall semester students in this population display large shifts in anticipated majors of study, while spring semester students' anticipated majors of study largely remain constant. Future work with respect to explanation construction in this preparatory chemistry population may also include demographic correlations, as this is a population of students primarily composed of female students.

A conceptual inventory to measure preparatory student knowledge is still needed for this population of students. Future work will include developing assessment items specific to preparatory chemistry courses with a broad range of chemistry concepts in order to more accurately assess conceptual understanding of these students.

Relating to the affective components of this study, future work should contain a larger number of constructing explanations activities in order to obtain a full assessment of changes of attitudes and self-concepts among students. As vicarious experiences have been shown to impact self-efficacy, and thus attitudes and self-concepts, it is important to increase the number of those experiences through development of more CER activities for student use (*17;18*). In addition, future studies of this population of students may be assessed utilizing an abbreviated version of the attitudes inventory, the ASCIv2, in order to reduce assessment fatigue (*19;20*).

Corresponding to the work on the electronic learning tool, Spheres, much more research must be conducted. R-analysis on the order of representation using strings and patterns of strings must be completed for all collected data and all four reactions (*21*). The difference between preparatory and general chemistry students on order of drawing each chemical reaction needs to be explored, both quantitatively and qualitatively; it is also important to also understand if this order of drawing has an effect on ultimate correctness of the particulate level drawing. In addition, experts must complete Spheres for expert-level comparisons to the population of students, and an eye-tracking study should also be completed during student use of Spheres to better understand students' cognitive processes and conceptual understanding throughout the use of the ELT. Finally, a feedback generation code should also be added to Spheres which can immediately provide students with feedback and solution explanations; this will allow for the probing of Spheres as an intervention tool within a population of students.

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