USING CLAIM-EVIDENCE-REASONING (CER) IN AN UNDERGRADUATE CHEMISTRY CLASS: AN EXPLORATION OF CER CONSTRUCTION AND RACE GENDER AND STATUS

by

LASHAWN A MCNEIL

(Under the Direction of Julie A. Luft)

ABSTRACT

The purpose of this study was to examine how small groups of students in an introductory undergraduate chemistry course construct CERs and the influence of race, gender, and perceived status during this construction. The small groups of students engaged in three chemistry activities that required them to generate a claim, evidence, and reasoning (CER) pertaining to each activity. The activities focused on gas laws, solutions, and buffers. The last activity was the focus of this study. This activity was selected because students were experienced in CER construction and had worked with their group members over the course of the semester. This was a purposeful point to collect data given the focus of the study was on CER construction and how the students influenced this construction. Overtime, the students established their group norms and were experienced with CERs. The study design involved the collection of qualitative data, which included written artifacts, participant observations, and audio recordings. The students (n=14) were enrolled in the undergraduate introductory chemistry course the used the CERs. The data were analyzed to understand the quality of the CERs that were constructed by the students, and the interactions of the students in their small groups and their perceptions of one another. A rubric was used to analyze the CERs, while Scott et al.(2006) and Hoon and Hart (2007) were used to analyze the discourse in groups and the CERs. The findings of this study revealed that as participants move from individual to small groups their CER construction improved, the students improved in their CER use, the ideas represented in the CERs generated by the groups were more blended and explanatory, the males were more dialogic in their interaction while females were more authoritative, and gender was important in to consider in CER construction. From this study, it is evident that CERs add to the collection of active learning instructional techniques. In this study, they allowed students to interact with one another regarding important ideas in science. However, more studies are needed around CERs and in understanding how the groups work with one another.

INDEX WORDS: Small Groups, Race, Gender, Perceived Status, Undergraduate Chemistry, Claim Evidence Reasoning, CER

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by

LASHAWN A. MCNEIL

B.S., NORTH CAROLINA A&T STATE UNIVERSITY, 1998

M. Ed., FLORIDA A&M UNIVERSITY, 2008

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LASHAWN A. MCNEIL

Major Professor:	Julie A. Luft
Committee:	Scott J. Dantley
	David F. Jackson
	Dorothy Y. White

Electronic Version Approved:

Ron Walcott
Vice Provost for Graduate Education and Dean of the Graduate School
The University of Georgia
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DEDICATION

“If you want a thing bad enough to go out and fight for it, to work day and night for it, to give up your time, your peace and sleep for it. If all that you do is dream and scheme about it, and life seems useless and worthless without it.

If you gladly sweat for it and fret for it and plan for it and lose all your terror of the opposition for it. If you simply go after that thing that you want with all your capacity, strength and sagacity, faith, hope and confidence and stern pertinacity.

If neither cold, poverty, famine, sickness nor pain of body and brain, can keep you away from the thing that you want. If dogged and grim, if you besiege and beset it, and with the help of God, YOU WILL GET IT!” — L. Brown

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CHAPTER 1

INTRODUCTION

Present Problems in the Field

The lack of interest and participation in science, technology, engineering, and mathematics (STEM) fields has been a longstanding problem facing the field of science education. In the 21st century, new societal demands require an effective and knowledgeable STEM workforce. As an advancing technological society, more citizens will need to be scientifically literate to make decisions about, for example, getting vaccines or proceeding amid climate change (Olson & Riordan, 2012). Also, people are needed who are skilled in the science disciplines to tackle energy consumption and environmental systems problems (Xue & Larson, 2015). Projections show that the United States will require more than a million more STEM professionals over the next 10 years if this country is to continue to be an international leader in technology and science (Olson & Riordan, 2012). To meet these challenges, colleges and universities will play a significant role in producing the students needed to fulfill the shortage of STEM workers.

In 2008, STEM majors accounted for only 14% of all undergraduate majors in the United States (Chen, 2015; Snyder & Dillow, 2013). Compounding this small number is the rate of attrition, which among STEM majors in colleges and universities is significantly high. Between 2003 and 2009, 48% of students seeking a STEM degree either changed their major or left college without completing a degree or certificate (Chen, 2013). Among those who changed their field, more than half went on to earn a degree in a non-STEM field upon graduation (Hayes et al.

2009; Wilson et al. 2012). While these data are disheartening, the data for minority student participation in STEM is significantly worse.

Additionally, the achievement gap that minority students experience in STEM fields must be addressed. Within this group, Black and Latino students leave at a higher rate than their White peers (Riegle-Crumb et al., 2019). Researchers found that 30% of Black students who entered college as a STEM major were still in STEM by their third year of college when compared to their White peers (Price, 2010), while only 8% of Latino students graduated with a STEM degree (Peralta et al., 2013). The attrition of Black and Latino students at the undergraduate level is only found in STEM fields. No other fields experience this specific phenomenon (Riegle-Crumb et al., 2019). In addition, only 38.1% of minority students who continue beyond their undergraduate degree receive a doctorate in a STEM field versus 51% of nonminority students (Allen-Ramadial & Campbell, 2014; Hurtado et al., 2010).

For students who leave their STEM major, the problem is not that they are incapable. Rather, they face social and academic barriers (Hurtado et al., 2010). Among the many barriers minority students face, there are two areas that are relevant to this study. One barrier is the relevance of science coursework to students' everyday lives (Hurtado et al., 2010). Course work that requires applying knowledge and experiential learning are key factors in mitigating social and academic barriers. These experiences often involve real-world problems and a group of students working toward a potential solution to the problem. In engaging in these real-world problems, data analysis is a key factor. Hurtado et al. (2010) found that students who engaged in undergraduate research experiences (which are real-world problems) were more likely to pursue advanced degrees in science. The opportunity to experience and engage in science through research experiences contributes to a student's confidence and science identity, which can impact the academic trajectory of underrepresented minorities.

Another barrier pertains to the use of traditional instructional approaches that fail to allow students to engage purposefully in the course content. Traditional instructional approaches limit opportunities for students to learn and understand science, which threatens their persistence in the field. According to Xu (2016), enhancing faculty members' ability to teach and engage students in their learning can help increase the persistence of STEM majors. Different instructional approaches that allow students to engage in the content purposefully during lectures, discussions, and laboratories have been shown to contribute to the persistence of STEM majors (National Research Council [NRC], 1997). Within these different approaches to undergraduate instruction, students should have opportunities to generate explanations from data, discuss conclusions collaboratively, or analyze data. Ideally, through these different approaches, undergraduate students can develop an understanding of how to do science while also engaging in the practices of science. Again, with this change in instruction, minority students in STEM majors will benefit and potentially be retained in the field.

Other barriers minority students face in STEM majors that must be addressed by colleges and universities are worth mentioning. The lack of diversity among faculty members is a barrier in the recruitment and retention of underrepresented minorities in STEM majors (Miriti, 2020). The diversity among faculty members within a college or university reveals the degree the importance of including all views and perspectives. When students experience diverse faculty members in their classes, they begin to see what is possible and know that all views and perspectives are valued.

In addition, minority students are often evaluated with stricter guidelines. These intended or unintended biases result in a limited evaluation of the work of the student. Along with the evaluation of the instructors, minority students also experience more skepticism about their abilities, which they may internalize as the potential to fail the course (McGee, 2020). Unequal evaluation by instructors and the skepticism of peers can be daunting for minority students who already face social and academic barriers and can further decrease minority students in STEM majors. While these two additional areas are to significant consider, they are outside the scope of this dissertation.

More recently, the President's Council of Advisors on Science and Technology (PCAST) reiterated the importance of undergraduate STEM education and offered general recommendations that specifically embraced a new vision of undergraduate education (Olson & Riordan, 2012). These principles included the following:

1. Catalyze widespread adoption of empirically validated teaching practices.
2. Advocate and provide support for replacing standard laboratory courses with discovery-based research courses.
3. Launch a national experiment in postsecondary mathematics education to address the math preparation gap.
4. Encourage partnerships among stakeholders to diversify pathways to STEM careers.
5. Create a Presidential Council on STEM Education with leadership from the academic and business communities to provide strategic leadership for transformative and sustainable change in STEM undergraduate education.

The first recommendation is important to this dissertation, and it reiterates earlier concerns for student-centered and authentic science instruction. This recommendation calls for empirically validated teaching practices to improve student achievement. This recommendation calls for the use of active learning, which is an alternative instructional approach to traditional classroom lectures (Olson & Riordan, 2012). While a body of research about the importance of alternative types of instruction has emerged (Wilson et al., 2012), studying different instructional approaches that fall under the active learning umbrella is still essential.

In colleges and universities, changing the instruction of STEM classes can affect student interest and persistence in STEM fields. Research has shown that traditional lecturing is not as effective as active learning. Students in a lecture-based course are one and a half times more likely to fail than those in a course where active learning is the primary method of instruction (Freeman et al., 2014). Lectures do not promote higher order thinking skills, and they are often considered to be an ineffective teaching strategy that must be changed in an instructor's instructional repertoire.

Active Learning as an Instructional Approach

Active learning instruction is the alternative, and it involves students engaging in their learning by solving problems, analyzing data, or collaborating with their peers (Cavanagh et al., 2018; Handelsman et al., 2007). Active learning has been shown to increase higher order thinking skills and improve academic learning outcomes, which results in students improving their performance on exams by up to half a letter grade (Freeman et al., 2014). According to Prince (2004), active learning also increases the retention of students in courses, enhances the transfer of information from instructor to student, positively influences student motivation, improves interpersonal skills among students, and decreases academic failures among students (Prince, 2004; Tendhar et al., 2019).

As an instructional strategy, active learning has been shown to affect positively the ways students engage and persist in science. A 2011 study of 1,091 students revealed that active learning strategies increased student retention and engagement with course material during the semester (Smith & Cardaciotto, 2011). Moreover, Almarghani and Mijatovic (2017) concluded that active learning improved student perceptions about science as time passed, which resulted in greater classroom participation and student engagement in the course. By increasing student engagement and retention in science and STEM courses, greater knowledge and appreciation about science was cultivated among students.

Additionally, active learning provides opportunities for students to build cooperative skills for working in group settings. Active learning strategies require that students work together to address a problem or suggest a solution. As students work together, students create a productive classroom that will support further investigations (Bachelor et al., 2012). Improved student cooperation and a productive classroom environment result in increased student engagement and participation in the science classroom. In 2004, a seminal study reinforced that active learning improved interpersonal skills associated with working in groups and enhanced the transfer of knowledge between students (Prince, 2004). This study was a review of the literature that examined the effectiveness of active learning.

Active learning instruction has many benefits. It can increase the number of minority students pursuing STEM careers, resulting in more minority leaders in STEM fields. Active learning can help students develop the thinking skills needed to make decisions about current STEM-related issues. These skills are important as communities contemplate the value of vaccines or the impact of climate change. Additionally, undergraduate STEM classes need to be taught in new ways that ensure all students have access to a future that is connected to STEM subjects. Researching these approaches and their impact on minority students is an important part of the national call to action.

An Instructional Solution

The Claim Evidence and Reasoning (CER)Framework developed by McNeill and Krajcik (2008) guided this study. The development of the CER framework was influenced by the *National Science Education Standards* published by the NRC in 1996, and the more recent *Next Generation Science Standards* (NGSS; NGSS Lead States, 2013). Additionally, the 2012 PCAST Report's first recommendation was to catalyze the widespread adoption of empirically validated teaching practices to improve science education (Olson & Riordan, 2012).

The NGSS identifies explanation as an important practice that students should experience (NGSS Lead States, 2013). The explanation is described as "the construction of theories that provide explanatory accounts of the world which includes a claim that relates how a variable or variables relate to another variable or a set of variables" (p. 394). The ability to construct explanations using evidence is a critical component in understanding scientific concepts.

According to Novak et al. (2009), a claim answers a research question that a student is answering during an investigation. The evidence is data that are gathered, selected, and used to support a claim (McNeill et al., 2006). Reasoning justifies why the data serve as evidence to support the claim (McNeill & Krajcik, 2009). Each component of the CER framework allows students to develop a more complete explanation by requiring them to analyze and critically evaluate the connection between their claim and the data.

The use of evidence requires students to use their reasoning to determine how the data or observations support their claim or assumption about scientific phenomena. When learners view the evidence as a priority, they can accurately evaluate and develop scientific explanations (Aguilar, 2015; NRC, 1996). Supporting an explanation using evidence is an essential component of doing science. The ability to effectively evaluate data as evidence further supports a student's science process skills. Arguing, defending, and reconstructing knowledge are some of the most important practices of science. When students can construct better scientific explanations, they gain a deeper understanding of the conceptual knowledge and theories associated with topics they are exploring.

Along with the use of CERs is the use of small, interactive groups. Working in small group settings has shown itself to benefit undergraduate students in many ways. This use of the various forms of small-group learning has effectively enhanced academic achievement, attitudes toward learning, and student persistence in science (Springer et al., 1999). Peer learning that occurs in small groups is an instructional approach that can transform the learning environment of students (Blumfield et al., 1996). Science educators have encouraged the use of small interactive groups to enhance the instruction of science in classrooms.

Purpose

The purpose of this study was to examine how small groups of students in an introductory undergraduate chemistry course construct CERs and the influence of race, gender, and perceived status during this construction. The focus of this study was on the use of active learning in an undergraduate introductory chemistry classroom. Specifically, it was the exploration of how an active learning approach impacted student learning. This study focused on understanding the unique role that groups played in supporting the construction of student knowledge. In groups, students are influenced by many factors as they engage in a problem and communicate various aspects of the problem with their peers. These factors include the gender of the group members, their academic status, and their race. Each factor may influence how knowledge is constructed in a group setting.

Research Questions

The overall research question for this study asked, "How are scientific explanations constructed using the CER framework in an undergraduate chemistry course?" This question resulted in a study that was designed to understand how CERs were constructed in small groups and the influence of race, gender, and perceived status during this knowledge construction process. The research questions emerged from this broader question, which was, "How are CERs constructed in small groups in an undergraduate introductory chemistry course? And does gender, race, or perceived status make a difference in CER construction?"

These research questions provided science educators and science instructors with evidence about the use of active learning in the classroom. With this evidence, more students may be impacted as STEM instructors are reminded of the importance of active learning, which may result in a more diverse STEM workforce.

Why This Study Matters

This research adds to the existing literature in active learning, CER, and the role of race, gender, and status on student learning in active learning environments. Currently, minimal research has addressed the relationship between active learning strategies and the influences of race, gender, and status in undergraduate chemistry settings. With the knowledge attained from this study, better implementation of active learning approaches may surface and contribute to understanding how to increase student interest and retention in science at the undergraduate level.

The Impact of this Study

The findings of this study impact the field of science education by helping science educators understand how students generate explanations and how the composition of their groups influences the final explanation. This study was connected to undergraduate chemistry courses, which are STEM fields. The findings can also instruct science educators about how to implement the CER framework as an instructional strategy in an undergraduate chemistry classroom. This study provides a general framework that was used in an undergraduate class and can be replicated by other instructors. Finally, this study contributes to research in the field of active learning. This is a field that continues to need additional investigations to fully understand how active learning can exist in classes and its impact on students.

This study consists of five chapters, including this one, which presented a general rationale for the study. The next chapter is a literature review (Chapter 2), which focuses on active learning, CERs, and learning in groups. The methods chapter (Chapter 3) explains the context of the study, the participants, the data collection process, and the data analysis, The results of the analyses of data are presented in Chapter 4 and include the presentations of quantitative and qualitative data. The last chapter (Chapter 5) summarizes the findings and contains the practical implications and further research. The discussion is followed by references and appendixes.

CHAPTER 2

LITERATURE REVIEW

The need for effective instructional strategies is an ongoing problem in the field of science and science education. Science educators and national organizations have called for the implementation of instructional strategies that employ the use of active learning techniques in the science classroom. This review of literature focuses on four areas of science instruction (active learning in undergraduate education, small group learning, Claim Evidence Reasoning (CER) and Generative Learning Theory) that are relevant to this study. For the areas of small group learning and CER, research in each of these areas is accompanied by relevant studies on race, gender, and perceived status. These areas provide important background to this study, which is focused on how an active learning environment can contribute (or not) to the learning of diverse groups of students. Each review area is presented, and then a summary highlights the important aspects of the review to this study.

This chapter begins with a description of active learning and how it has evolved from its beginnings to present. This discussion is followed by an examination of the advantages, disadvantages, and gaps in the literature surrounding active learning. Following this discussion is an examination of the literature related to small groups in classrooms, the use of CER as related to undergraduate science education and an overview of the Generative Learning Theory. Race, gender, and perceived status will also be addressed within these reviews. These reviews have the goal of highlighting the need for research in CER in the undergraduate classroom and suggesting the contribution that can be made to these fields.

Active Learning

Active learning is the process in which students engage in their learning by discussing, refuting, arguing, and debating with others the content they are studying. Active learning is composed of classroom instructional strategies that require students to participate in and think about the presented content (Bonwell & Eison, 1991). It involves students participating in their learning by doing activities in class – other than simply note-taking and following directions (Handelsman et al., 2007). Freeman et al. (2014) defined active learning as student engagement in the learning process through participation in class discussions and activities that promote higher order thinking through group work. Regardless of how students are involved in this process, active learning strategies and activities take place in the classroom and strive to increase the cognitive engagement of the students (Freeman et al., 2004).

The Pause Procedure is an example of an active learning strategy that is often used in college courses. During the Pause Procedure, the instructor stops at different points throughout the lesson to allow students time to discuss the content being taught (Richards et al., 2017). These pauses allow students time to contemplate the presented material, which results in their improved content knowledge (Ruhl et al., 1987). In a 2017 study, the Pause Procedure was used during 48 lecture presentations by implementing a 1-minute pause in the middle and at the end of each presentation. The researchers concluded that students were able to recall more content when compared to traditional presentations (Richards et al., 2017).

Peer Instruction is another type of active learning strategy. Peer Instruction is a method that requires students to read the content before class. When students come to class, they engage in group discussions guided by questions or activities about the course material (Deshpande, 2019). Zhang et al. (2017) showed that Peer Instruction improved student attitudes and beliefs about Physics when compared to courses traditionally taught through lectures. In Carstensen et al. (2020), Peer Instruction in a pharmacodynamics course showed a significant increase in the number of students achieving 50% on course assessments.

The Origin of Active Learning

Active learning dates to the 4th century BC, over 2,000 years ago. The Greek philosopher Socrates used active learning strategies while instructing his students. In his instructional sessions, he gave constant feedback to students in the form of questions. This form of instruction is known today as the Socratic Method. For example, in science classrooms, the Socratic Method is used to discuss experiments and specific topics. During the time of Socrates, it was possible to use this active learning approach because the number of students in each class was small. However, lecturing has become a more commonplace practice in today's classrooms to accommodate the significantly higher number of students in classrooms.

Research in the 1990s on student learning revealed that traditional lecturing was not an effective form of classroom instruction (Baepler et al., 2014). Studies revealed that students only memorized terms or procedures and often did not have a good understanding of the presented topic. The term "active learning" was first introduced in 1991 by Bonwell and Eison in their ASHE-ERIC Higher Education Report, *Active Learning: Creating Excitement in the Classroom*. The authors discussed the diverse ways that active learning could be implemented in the classroom and suggested that students engage in classroom activities requiring them to read, write, and discuss problems using higher order thinking skills (Chickering & Gamson, 1987). This approach initiated a discussion about new ways to teach in higher education, as well as a line of research that explored active learning.

The use of active learning has grown significantly over time, and its use can be seen in institutions of higher education across the country (Seeling et al., 2019). Many universities have adopted active learning approaches due to their positive influence on student learning. To support the expansion of active learning in higher education, funding is now being devoted to building classrooms that promote active learning environments in collegiate academic settings. Along with this expansion is a focus on research about active learning in higher education. Specifically, studies are being conducted to understand teaching, learning, professional development, and curricular design that is associated with active learning in higher education (Borte et al., 2020).

Research About Active Learning

In this review, the terms "active learning" and "undergraduate education" were specifically used as search terms in the abstract for peer-reviewed papers in ERIC, Academic Search Complete, Education Research Complete, Google Scholar through the university library system, and Psychnet from 2015-2021. A seminal meta-analysis published in 2014 by Freeman et al. unequivocally identified the value of active learning, which is why this search looked for studies after 2014.

In this search, only peer-reviewed papers that focused on undergraduate science courses were reviewed. The initial search resulted in 119 papers, of which 10 were identified for inclusion because of their orientation toward active learning. A second search using Google Scholar with the key terms "active learning," "science," "gender," "race," and "equity" was completed. The top 40 articles focusing on active learning were reviewed.
Another 25 articles were located through a secondary search, which involved the key terms of "race," "gender," "status," and "equity."

The final selected papers resulted in a definition of active learning that was used in this study. Miller and Tanner's (2015) definition was most salient to this study. They defined active learning that expanded upon the description offered by Freeman et al. (2014). Miller and Tanner specifically stated that active learning involves "constructing meaning, examining prior ideas, and resolving conceptual confusions, just as scientists do in their efforts (p. 3)." Active learning can occur among individuals or groups, but it requires students to understand concepts and processes (Asniza et al., 2021).

Miller and Tanner (2015) along with other authors (e.g., Erol et al., 2015; Styers et al., 2018), suggested instructional approaches that can support active learning in the classroom, which included:

- Think-Pair-Share – Students talking about their ideas with one another.
- Minute papers - Students writing about a learning experience.
- Clickers – Devices that allow students to express their understanding, which can help them reflect upon what they will be doing later in the lesson.
- Group work – Students work in groups to solve problems.
- Cooperative learning – Students working collaboratively to solve problems.
- Case-based learning – Students examining real-life cases.

Advantages of Active Learning

Before 2015, many studies demonstrated numerous benefits of active learning. Prince (2004) in a seminal analysis of research on active learning concluded that students were more engaged in their learning, which resulted in improvements in their knowledge and their views of science. He also suggested that the positive experiences of the students could result in their persistence in STEM fields. The other seminal study by Freeman et al. (2014) concluded that students in active learning classes improved their understanding of the presented content, which resulted in a 6% increase in their exam scores. Freeman et al. (2014) also concluded that students in traditional lecture sections were 1.5 times more likely to fail their class. The significance of this study was specifically reported as follows:

> The studies analyzed here document that active learning leads to increases in examination performance that could raise average grades by half a letter.... The analysis supports a theory claiming that calls to improve the number of students receiving STEM degrees could be answered, at least in part, by abandoning traditional lecturing in favor of active learning. (p. 1)

The value of active learning continues to be documented in studies since this report, and these are discussed in the following pages.

***Improved Motivation to Learn*.** Bull et al. (2020) examined how active learning in a large introductory Microbiology course affected students. In their study, the students were placed in groups of three and assigned to create posters on the topics of their choice. Different pre- and post-measures were taken and resulted in the authors concluding that the collaborative poster creation resulted in students becoming more intrinsically motivated to learn, as opposed to extrinsic motivation that occurs when tests are given. The students appreciated the opportunity to seek out information about their topic, and it was motivating for them.

Similarly, Owens et al. (2017) found that an active learning environment that emphasized constructing explanations, engaging in argument from evidence, and obtaining, evaluating, and communicating information was motivating for students. In their study, they drew upon an online platform and in-class work to create an active learning environment. The students generated their questions, constructed explanations, and engaged in argumentation. Throughout the process, the students received feedback from the instructor. In an analysis of interviews, the students reported that they were motivated because they could be creative during the lesson and that they could work with their peers to learn the material.

Improved Learning of Content. Several studies have continued to examine student learning of the content (e.g., Bull et al., 2020; Chen et al., 2016; Cleveland et al., 2017; French & Burrows, 2017). For instance, Bull et al. (2020) sought to improve student learning of the content in their class by having students create posters about a topic of their choice but associated with the class. They had students work in groups and required that the students interview scientists and consider how science works. At the end of the course, they concluded that when students selected a topic and worked together, their understanding of the topic improved. In addition, they were able to connect their new knowledge to science events in the news.

In an undergraduate course focused on medical topics, Chen et al. (2016) engaged students in medical cases to learn about pathophysiology. Over 400 students, over 3 years, completed the assigned cases in small groups. During these cases, the students worked together to understand the medical condition associated with the 1957 pandemic and make a medical recommendation. The students who engaged in the cases demonstrated a significant shift in passing grades toward higher grades. In another study of an active learning case intervention study, Serrano et al. (2016) found that students learned about the process of doing science (another form of content knowledge) as they engaged in a case about the 1957 pandemic. The students had opportunities to make explanations from evidence and analyze collected data. This activity improved their scientific process skills.

It is well-documented that active learning strategies promote the critical construction of knowledge and reflection on knowledge (Silva et al., 2020). By implementing active learning strategies in higher education science courses, students can achieve higher learning gains conceptually. For instance, in a 2020 study, 36 students in a nursing course were divided into seven small groups to create a documentary as a course assignment. The resulting data showed that the documentary process involved active learning and turned out to be a valuable teaching and learning tool for students (Silva et al., 2020).

The addition of active strategies enhances student learning and engagement in the classroom. French and Burrows (2017) created an interdisciplinary course for undergraduates that involved different active learning strategies, which focused on using models, conducting experiments, and collecting and interpreting data (standards important in science education). By the end of the course, the students engaged in different active learning strategies. As a result, the researchers concluded that the students significantly improved their knowledge of the content presented in the course.

Critical Thinking Is Improved by Active Learning. Styers et al. (2018) used a collection of strategies associated with active learning to support students in learning to think critically. These strategies comprised 20% of the class time and included think-pair-share discussions, clickers, and group problem-solving. During the undergraduate courses in cell and molecular biology, evolutional ecology, and biochemistry, students took a pre- and posttest to evaluate their critical thinking skills. The students who engaged in the active learning strategies showed gains in their critical thinking skills, with upper-level students gaining the most. Males and females exhibited similar gains, while underrepresented minorities had a greater gain in critical thinking than their White counterparts.

Improved Student Cognitive Factors. Different studies have explored how students benefit beyond content knowledge acquisition. These different cognitive factors are related to mindset, motivation, and confidence – to list a few. For instance, Xiaoshan et al. (2020) conducted an exploratory mixed-methods study to evaluate student learning. They used focus group discussions and online surveys for their data sources. The analysis of data revealed that active learning settings promoted positive mindsets, encouraged class participation, mutual learning, and improved peer relations. By implementing active learning strategies in the classroom, cognitive factors such as mindset, motivation, and confidence were positively affected and increased student achievement.

In the area of confidence, Wiles (2016) used visualizations in her study of active learning experiences for students. The lesson began by having the lecturer introduce the students to a figure or figures central to the lesson. The students then discussed their observations with their peers. The lecturer summed up the observations of the students afterward. The students then reported how the process supported their learning. The surveys indicated that as students worked together to analyze figures, they developed more confidence in their ability to interpret the figures. More importantly, female students reported increased confidence in their interpretation of figures.

Technology as a Support for Active Learning. One area of research that expanded in the last few years involves the integration of technology into courses to promote active learning (e.g., Asniza, et al., 2021; Donkin & Kynn, 2021). In Asniza et al. (2021), pre-university college students engaged in the free online program Kahoot. This program has games, quizzes, and discussions that are meant to engage students in their learning. Students could work individually or collectively. In this study, the students who engaged in Kahoot reported positive perceptions in using technology – with important gains occurring with small groups of students working together.

Improved Interpersonal Skills. The instructional approaches of active learning encourage teamwork among students and promote the development of interpersonal skills, which include communicating with their peers (e.g., Asniza et al., 2021; Chan et al., 2016). In an active environment, students refute, argue, and discuss science content with other students in the class, resulting in the development of students' ability to communicate their thoughts and to learn from their peers. Asniza et al. (2021) found that students developed their communication skills as they analyzed data and then had to communicate their understandings to their peers. They added that learning to communicate effectively is a key component of active learning.

Active Learning Benefits Poor Performing Students. Active learning can be beneficial to students who traditionally do not do well in science. Kressler and Kressler (2016) specifically explored underrepresented and non-represented students' perceptions of active learning in a large-enrollment STEM class. Their class focused on kinesiology and was required for all majors. It has been a bottleneck in terms of students advancing through the major. In their mixed-methods analysis of survey and interview data, they found that many of the students perceived active learning as beneficial yet challenging. All students had similar achievement levels in higher order thinking, regardless of ethnicity and race. Again, students found active learning difficult, yet they all benefited by engaging in active learning opportunities.

Summary. Active learning is viewed as having many benefits beyond the learning of science content. Since the Prince (2004) and Freeman et al. (2014) reports, there has been an ongoing emphasis on measuring students' knowledge growth in active learning environments. This emphasis is not needed, as active learning has been shown to support student learning of content by positively affecting interpersonal skills (Asniza et al., 2021), student engagement, confidence (Wiles, 2016), and critical thinking skills (Styers et al., 2018). Research supports the idea that active learning is a necessary component of effective classroom instruction. More importantly, it has a positive effect on the learning of students who typically do not take science courses or persist in science majors.

Disadvantages

The studies that were reviewed revealed data about the disadvantages of active learning. Often this data emerged through interviews and studies that sought out the opinions of students who were engaged in active learning. Identifying and discussing the disadvantages of active learning is important in the implementation and use of active learning in the science classroom.

Active Learning Results in Negative Attitudes. Research has revealed that active learning can cause negative shifts in attitudes toward science. Cleveland et al. (2017) compared two courses that used different active learning methods. The courses were large-lecture-style classes, and they used either graphic organizers or clicker-based case studies. Regardless of the class, the students had negative shifts in their attitudes and motivation in science. These shifts were the result of experiencing a new learning format.

Owens et al. (2017) created an online and in-person active learning experience for undergraduates. While they reported some positive results in terms of motivation, they also found that many students were resistant to the active learning format. According to Owens et al. (2017), many of the students were unfamiliar with the instructional approaches that were utilized in the class and did not like the extra effort that was required. Many students disliked the uncertainty associated with the lesson. In general, students preferred the teacher-centered environment that they experienced previously.

Institutional Barriers Can Limit Active Learning. Many different institutional barriers can constrain active learning. In some instances, the physical classroom presents a barrier to implementing active learning strategies (Holec & Marynowski, 2020). College and universities classrooms are typically structured for large, lecture-based courses where faculty members deliver information to audiences of students.

University faculty and academics also experience barriers that prevent them from implementing active learning strategies (Kim et al., 2019) or make it difficult to implement class discussions. These barriers can be related to the mandated curriculum, which is associated with the accreditation of the institute of higher education. Or it can be related to the structure of the classroom that has students sitting in rows and unable to talk to one another. This traditional setting is not designed for groups to work together and conduct class discussions.

The seminal studies of Freeman et al. (2014) and Prince (2004) highlighted that faculty members have problems enacting active learning and recognizing active strategies in the classroom setting. One of the findings from these studies was that one of the major obstacles in the implementation and the use of active learning at the university level is faculty understanding of active learning, which can be attributed to the lack of professional learning opportunities provided for faculty members at their institutions. Additionally, even when faculty members learn how to use active learning, they are often skeptical that students can acquire the content knowledge emphasized in class using active learning strategies (Murillo-Zamorano et al., 2021). This skepticism is based on two areas: (a) faculty members believe that some content must be shared through traditional methods because active learning would be ineffective, and

(b) faculty members believe that students need to learn a significant amount of content before they can progress to the next topic.

Active Learning Does Not Benefit All Students. Higher level students may not benefit from the use of active learning strategies in the course. A 2020 study of a large microbiology class found that the implementation of active learning was challenging for all students. In this study, active learning strategies were placed in PowerPoint electronic slideshow presentations to support the students' learning of important concepts in microbiology. However, the students who typically had higher grades struggled the most with active learning approaches (Bull et al., 2020). In the active learning environment, it was not clear to high-level students' what content they should learn. They wanted the information they needed to learn to be shared with them directly.

In addition, Gin et al. (2020) sought to understand if active learning programs accommodate students with disabilities. In this study, they interviewed disability resource directors, instructors, and students to determine if they perceived challenges in active learning. The analysis of the interviews found that most active learning settings were problematic for students because the instructional modification was made only after the student experienced a need for the modification. That is, instructors did not proactively consider if their active learning approaches hindered the learning of students with disabilities. When this was determined by the study authors, they made recommendations about how to improve science classes for students with disabilities.

Summary. The challenges that face the implementation of active learning strategies are institutional barriers that exist in higher education, educators' view of students learning, educators' knowledge of active learning, and students' experiences with new instructional strategies. Addressing these barriers will play a key role in the effective implementation of active learning strategies in higher education to ensure all students benefit academically.

Gaps

There are areas in the literature on active learning that require further investigation. These gaps represent areas of research that have minimal or no research. The areas that must be addressed surround issues of student interactions and diversity in the science classroom. These areas are important topics in active learning that must be researched more if students are to experience the benefits of learning in an active setting.

One gap in the research pertains to student interactions. Within student interactions, it is important to understand what factors influence the productive interactions of students and how these factors influence their learning. Xiaoshan et al. (2020) specifically concluded that limited research has examined the interactions taking place in active learning settings and the way these interactions affect student learning. This review agrees with Xiaoshan et al., and limited research was found in this area. However, it may have been a result of the search process. Looking at the interactions of students is important because student interactions are essential to making sense of the knowledge presented in class.

Limited research has examined the intersection of race, gender, and status in active learning settings. The need to study this area is especially important in that the STEM field continues to be dominated by White males. Without a diverse field, new solutions will not be envisioned. To improve the diversity in STEM fields, the widespread implementation of active learning strategies is essential in the science classroom (Ballen et al., 2017). However, it is important to understand how diverse groups of students make sense of important concepts in science – a question considered in this dissertation.

Small Groups

In higher education, small groups are common in many active learning environments. In science classes, students either form groups in spaces that are designed to work in small groups, or they are placed into groups in lecture-based settings. Small groups are two or more individuals interacting for a shared purpose or objective. Small groups are often described as instructional settings that improve instructor learner ratios and promote collaborative learning (Torre et al., 2017). The instructor-learner ratios are improved by including more individuals in the process of discussing the presented materials. Collaborative learning is promoted by having individuals work collectively toward a goal. Within small groups, the working environment helps to create a task-related atmosphere that supports all students through positive social interactions (Hirvonen, 2020).

The two most implemented forms of small groups are collaborative and cooperative small groups. Cooperative groups in education are student-centered and instructor-facilitated, where students work in structured small groups to facilitate their learning as well as the learning of other members of the group (Lie, 2002). The five essential components of cooperative learning include (a) positive interdependence, (b) individual accountability, (c) face-to-face promotive interaction, (d) interpersonal and small group skills, and (d) group processing (Johnson & Johnson, 1999). Positive interdependence is when students work together to accomplish the assignment. Individual accountability is when each student is needed for the group to work effectively. Face-to-face promotion involves the students supporting one another. Interpersonal and small group skills involve learning how to work in a group. Group processing is the reflection of the group on their ability to solve the problem.

Cooperative groups benefit students academically and socially. According to Johnson and Johnson (2015), cooperative learning when compared to other forms of supportive learning results in greater academic achievement and communicative skills. Munir et al. (2018) studied an engineering course that was converted to a flipped classroom to include cooperative learning strategies. It revealed that cooperative learning improved student communication and problem-solving skills. Additionally, a 2021 mixed-method study where 136 undergraduate students participated in a semester-long course that evaluated the effect of cooperative learning on academic achievement revealed that the implementation of cooperative learning strengthened student communicative skills and academic abilities (Keramati & Giles, 2021). These studies mentioned show how cooperative small groups benefit students both academically and socially.

Collaborative small groups in education typically have less structure than cooperative learning groups. When students form groups, they work in pairs or groups of three to four students to complete a task or specific objective (Ha & Kim, 2021). In small groups, students do not have established or assigned roles for group members. As a result, the interactions among the students are not structured around the reflection or positive interdependent interactions (as in cooperative learning). Without this structure, the conversations are driven individually by group members.

Collaborative learning is a result of the environment that is structured by the instructor. In higher education, instructors assign students to groups and assign the students roles to contemplate data, discuss their findings, or complete an assignment. Instructors help students build their skills to work collaboratively so that they can talk about the topic and build group knowledge through their social interactions (Curseu et al., 2018). In collaborative group settings, the level of learning is often determined by the engagement of students (Pinninghoff et al., 2017). This engagement allows students to discuss important ideas and advance their understanding of the topic. Collaborative settings have shown to promote the acquisition of student knowledge (Leung & Nakagawa, 2021).

The Origin of Small Groups

According to Bruffee (1996), the concept of collaborative learning began in the 1950s and 1960s. British teachers and researchers noticed that medical students who learned to make a diagnosis in groups made better medical judgments than those working alone (Laal & Laal, 2012). Those involved in medical education took note of the learning of students. More studies were conducted in these settings, and over time the process of small groups using case studies became more prevalent in medical colleges. In addition, today instructional strategies that promote collaborative approaches have begun to be more accepted in the field of medicine; although having faced many challenges (Pluta et al., 2013).

This research was a springboard for other disciplines. A search in Google Scholar reveals multiple collaborative group studies in English, mathematics, and science. These studies often look at the outcomes of collaborative groups that are related to student performance. In general, when students work in small groups, studies have shown that small groups improve student academic achievement (Kalaian et al., 2018), such as in laboratory science. These results have prompted many institutions of higher education to support the expansion of collaborative groups.

The talking that takes place in collaborative groups is the key component of student learning (Golub et al., 1988; Laal & Laal, 2012). As students talk to one another, they exchange ideas, share information, and make decisions. However, students in small groups need instruction about how to talk (Bianchini, 1998). In the absence of guidelines for conversation, students have inequitable contributions that impact their learning (Bianchini, 1998). Scott et al. (2006) has also noticed the different patterns of discourse and referred to them as authoritative or dialogic. Authoritative is when one person dominates the discussion in the group and is directing the group. Dialogic discourse is when there is more of an exchange of knowledge and information.

Research About Small Collaborative Groups

There were two parts to this review. In the first part of the review, there was a focus on collaboration, small groups, science, and education. These were used as key search terms in the abstracts of peer-reviewed papers in ERIC, Academic Search Complete, and Education Research Complete through the university library system. These terms were also used in Google Scholar. The review of the literature yielded 24 papers that were relevant to small groups and science education at the postsecondary level.

In the second part of the review, a second search was focused on small groups, collaboration, science, race, gender, status, and equity. This search was completed using ERIC, Academic Search Complete, and Education Research Complete through the university library system. These terms were also used in Google Scholar. This search yielded 12 papers in this area.

Advantages of Small Groups

The research on small groups is varied. Some studies look at how small groups benefit students, and some studies look at how students learn in small groups. Across all these studies, there is compelling evidence that small groups are beneficial for a variety of reasons. This section will discuss different ways in which small groups benefit students in the science classroom.

Small Groups Have Multiple Benefits. The benefits of working in small groups are numerous for students (Laal & Ghodsi, 2012). In collaborative settings, small groups work together to solve problems (Laal & Laal, 2012), and these collaborative tasks can improve student learning (Nieswandt et al., 2020). According to Cohen (1994), small group collaborations improve learning through the exchange of knowledge and information. The interactions that take place in small groups benefit students by allowing students to build their knowledge, get feedback from peers, and increase their academic confidence (Wright, 2021). However, during collaborative activities teacher support is still necessary to optimize student learning.

Among group members, Xiaoshan et al. (2020) found that when small groups were embedded into active learning, the group members learned together, had accountability to the group, and developed relationships with their peers. Xiaoshan et al.'s (2020) study specifically looked at student learning in active environments using group discussions and online surveys. This study revealed that small groups in active settings increase participation, accountability, and improved peer relationships.

At the student level, participating in small group discussions allows students to build their knowledge individually, and it provides opportunities to hear different views about the content being addressed (Smith et al., 2009). It also provides students with an opportunity to build their abilities to monitor and direct their learning (Jacques, 2003). An important study in this area (Williams & Svensson, 2021) examined the advantages and disadvantages of small group discussions of preservice teachers learning science content. Preservice teachers were provided their learning opportunity, which revealed that the understanding of science was gained through asking questions, testing ideas, and being exposed to different views (Williams & Svensson, 2021).

Race in Small Groups. Small groups promote the development of student interpersonal skills and allow students to form relationships outside of class. Small group activities promote racially diverse friendships among students. A study examining the experiences of 100 participants placed in small diverse groups during a local/national public deliberation event designed to examine their experiences during the event revealed that participants of color experienced better overall group communication and productivity than their White group members (Abdel-Monem et al., 2010). Additionally, the same study found that all participants, regardless of race, valued the opportunity to interact and be exposed to diverse group members. As a result of working in small groups, students form friendships that extend beyond the classroom and into their personal lives.

Gender Differences Exist in Small Groups. Differences have been found among genders during group activities, which impacts the participation and learning of students. This performance is related to the students' interactions. For example, Wieselmann and Dare (2020) studied fifth-grade boys and girls as they participated in engineering and science activities. The boys in the groups were more competitive and controlling and less concerned with the females' participation. Still, each student negotiated their purpose in the group that was related to what they contributed to the group. Wieselmann et al. (2020) concluded that group composition matters in terms of the interactions and learning of the students.

In a similar study, Aguillon et al. (2020) studied 40 lectures of eight faculty members over a year to look at student interactions. They wanted to determine if the different gendered students were interacting differently in the classes. Within the classes that implemented small groups, they found that after small group discussions male students volunteered more readily than did female students. The researchers attributed this finding to the concept of stereotype threat, in this case where female students believe males underestimate the academic ability of females.

The use of small groups provides a promising solution to gender issues in STEM fields, where females are underrepresented. As evidence, 513 students in an Engineering course were surveyed to examine gender similarities in self-efficacy and gender differences in collaborative activities (Stump et al., 2011). This study revealed that female students relied on collaborative instructional strategies more than male students did. The female students used collaborative practices to advance their understanding, while the male students worked individually.

Summary. The research that supports the implementation of small groups in the science classroom is clear. Small groups allow students to experience multiple benefits, such as improved interpersonal skills, increased learning, and academic confidence. In addition, student groups that are underrepresented in the field of science benefit from the implementation of small groups through student engagement and classroom discussions with peers. These advantages support the use of small groups in the science classroom as an effective instructional strategy for student success.

Disadvantages of Small Groups

Even though small groups have many advantages, some disadvantages emerge as students work together. The disadvantages that impact student learning, which contribute to the lack of students pursuing STEM majors or careers, will be discussed in this section. The studies in this area are varied and explore factors that influence how race, gender, and status interact with the factors that influence student participation and learning in small groups.

The Role of Status in Small Groups. Inequity within small groups arises from group member status and limits the learning of marginalized students (Jackson & Pak, 2019; Langer-Ozuna, 2011). According to Cohen (1994), academic status is the most influential form of status in the classroom. Status influences who and how individual members participate in small groups (Jackson & Pak, 2019). In male-dominated STEM fields, female group members have lower status than male group members, which creates challenges during small group collaborations (Misra et al., 2017) that influence group member participation.

Status and Talking in Small Groups. The talking that takes place is the key component of the learning that takes place in small groups. According to Bianchini (1998), group members who engage in more talking in small groups learn more. The turns of talk allocated to individuals within a small group are related to group member status (Bonito & Hollingshead, 1997). Individuals engage in different amounts of talk based on factors within small groups, such as status, that influence learning and engagement. High-status group members take part in more small group discussions than members with lower status, resulting in more learning for high-status members.

Unequal Benefits of Small Groups. Small groups do not benefit all students equally. For example, female and minority students benefit more from small group activities than other groups of students. Stump et al. (2011) found that female students engaged in more collaborative practices than did male students. By engaging in more group discussions and talking female and minority students learned more. In addition, academically stronger students are more likely to receive a lower grade (learn less) within small group settings due to the presence of academically weaker students (Yadgarovna &Husenovich, 2020).

The Inability to Monitor Small Groups. The inability to properly monitor students in small groups is a challenge faced in the science classroom. According to Yadgarovna and Husenovich (2020), a disadvantage of small groups in science is the inability of the instructor to monitor small groups in the classroom effectively. The ability to monitor small groups is a key factor in the acquisition of knowledge and ensuring that small groups function properly.

The Impact of Social Loafing. Working in small groups has been shown to promote social loafing among small group members. While working in small groups, some group members make a minimal effort during classroom activities and discussions (Rajaguru et al., 2020). Social loafing can adversely impact small groups by decreasing student learning through lack of participation or creating tension between group members by not completing assigned tasks.

Summary. The challenges that science educators face while implementing small groups are group discussions, ensuring equal benefit among group members, the ability to monitor small groups, and social loafing. Addressing these challenges is key to ensuring that small groups are implemented effectively in the science classroom so that all students become more engaged in the learning process.

Gaps

The gaps in the research on small groups focus on making relevant connections between school and the real world (Bianchini, 1998). More research needs to be conducted to ensure students can make connections to ensure that science is relevant. How small groups interact and collaborate to ensure meaningful learning takes place is another area that needs further research (Nieswandt et al., 2020). The interaction and collaboration that take place in group discussions have a major impact on student learning.

Additionally, further research should be conducted to evaluate gender-specific differences in small group participation, as well as how this participation takes place (Aguillon et al., 2020). It is important to address gender and diversity in small groups (McLeod et al., 1994). Also, research should be conducted to address the nature of member tasks and group function (McLeod et al., 1994). Understanding that these two aspects are key to improving the overall effectiveness of small groups is important.

Claims Evidence Reasoning

CER is a framework that was developed to support students during the process of creating a scientific explanation. Each component of the CER framework allows students to develop complete explanations through the analysis and critical evaluation of evidence in the form of data.

According to Novak et al. (2009), a claim answers a research question during an investigation. Claims are evaluated using different forms of information as well as ideas and are often correlated to specific science disciplines (McNeill & Berland, 2017), which include biology, chemistry, and socioenvironmental concerns. A complete and accurate claim uses relevant evidence as support and references scientific phenomena to connect the reasoning during the construction of a scientific explanation (Atkinson et al., 2020).

The evidence is data that are gathered, selected, and used to support a claim (McNeill et al., 2006; see also Andrews et al., 2016). These data are generated through scientific investigations or given in the form of data sets. Alegado and Lewis (2018) classified evidence as data gathered during classroom activities and experiments, or it can be content-related facts from various resources. Data becomes evidence when the data are linked to a claim designed to answer a question about scientific phenomena (Jackson et al., 2016). Evidence can be represented textually, visually, or numerically in documents or through investigative processes (Whithaus, 2012). The effectiveness of data to support a claim is an indication of its strength (Staley, 2004).

The reasoning process is a key step in the CER framework. Reasoning is justifying a claim with appropriate and sufficient principles showing how data represents evidence (Blank et al., 2016). Reasoning also serves as the connection between the claim and evidence, which correlates the two making the claim believable (Bugarcic et al., 2014). According to Yearwood and Stranieri (2010), reasoning is interconnected with individual rationale and based on the premise of selected principles and goals. The reasoning process demonstrates an individual's understanding of scientific phenomena.

The Origin of CER

The CER Framework was developed by Katherine McNeill of Boston College and Joseph Krajcik of Michigan State. The framework was developed as the answer to a call made by the *National Science Education Standards* (*NSES;* National Research Council [NRC], 1996). The *NSES* reinforced the importance of CER when it suggested that a scientific explanation requires the examination of data, comparison of data, identification of reasoning, and justification of a claim. The CER process is used by scientists when making sense of collected and analyzed data (McNeill & Krajcik, 2008).

The CER framework was started as a curriculum project that McNeill and Krajcik were implementing in the Detroit Public School System. This framework was designed to help students enhance their ability to create explanations about scientific phenomena. Over time, McNeill and Krajcik have revised the CER framework for K-12 students, while other science educators have enhanced the framework for higher education.

McNeill and Krajcik's creation of the CER framework was influenced by the work of Toulmin, who was a British philosopher and educator. Toulmin's work was influenced by the Austrian philosopher Wittgenstein. Toulmin studied moral reasoning and logic, which served as the foundation of Toulmin's Model of Argument (Jackson & Schneider, 2018). Toulmin's Model of Argument was developed as he examined cases from the British court system to determine the components of a successful argument (Ahmed & Sharaf, 2019). Toulmin found six elements present in each argument that made them successful (Gabriel et al., 2020): claim, grounds, warrant, backing, rebuttal, and qualifiers (Metaxas et al., 2016). Claim is the conclusion to a problem; grounds are evidence that supports the claim; warrants are the assumptions and scientific principles that are accepted as true; backing is the principles that support the warrant; rebuttal is a response to other individual's views or claims; and qualifier is the evidence that supports a true claim (Ahmed & Sharaf, 2019).

McNeill and Krajcik adopted Toulmin's Model of Argument to create the CER framework. The CER framework was designed to improve argumentation skills and support students as they construct knowledge about scientific phenomena (Fox, 2021). Drawing upon the work of Toulmin (1958) and Eduran et al. (2004), McNeill and Krajcik observed that scientific practices involved the use of evidence during arguments to connect claims using warrants and backings. These observations led to the development of the CER framework.

The CER framework was developed to improve the construction of scientific explanations. The framework was first used in the field of rhetoric and communication. CER has since moved from English to the science classroom in response to local, state, and national calls for science reform and reorganization of science standards.

Research About CER

In this review, the phrases, and terms "claim evidence reasoning," "claim-evidence-reasoning," "claim evidence reasoning framework," "claim-evidence-reasoning framework," "science," and "undergraduate chemistry" were used as keywords in the abstract for peer-reviewed papers in ERIC, Academic Search Complete, Education Research Complete, Psychnet, and Google Scholar through the university library system. This search resulted in 43 papers relevant to CER that were used for this study.

A second search was conducted in ERIC, Academic Search Complete, Education Research Complete, Psychnet, and Google Scholar through the university library system using the following key terms and phrases "race," "gender," "status," "equity," "claim evidence reasoning," "claim-evidence-reasoning," "claim evidence reasoning framework," "claim-evidence-reasoning framework," "science," "chemistry," and "undergraduate chemistry," which did not yield any additional papers to be used in this review.

Advantages of CER

The CER framework has been effectively used across different subjects and grade levels. Studies on CER show increases in conceptual knowledge, use of evidence during science investigations, and most importantly, better scientific explanations by students. The advantages of the CER framework will be elaborated upon in the following sections. These sections are a summary of relevant papers found in the search of the literature. This review will examine, among other areas, CER use across different subjects, how CER effects the conceptual understanding of students, and how CER in the classroom improves the quality of student explanations. A discussion of CER within argumentation is also included, which is another science practice that is highlighted in the NGSS (NGSS Lead States, 2013).

CER Influences Conceptual Understanding. Several studies have demonstrated the value of using CER to improve the conceptual understanding of students. The construction of scientific explanations and engaging in the argumentation process are essential components of scientific inquiry (Berland & Reiser, 2009; Driver et al., 2000). Often when students generate scientific explanations, their conceptual understanding is indirectly increased. Conceptual understanding involves concepts that are statements about phenomena (Novak & Gowin, 1984). In addition, conceptual understanding involves the ability to apply ideas to science situations, reason through core ideas, predict the behavior of science systems, solve science problems, and translate concepts across different science scales and representations (Holme et al., 2015). In studies of CER, conceptual understanding is often a result of the reasoning component or a separate assessment.

For instance, a Malaysian study implemented CER in a chemistry classroom (Heng et al., 2015). Students used CER to explain data about neutralization reactions in chemistry. After the students constructed their CERs, they presented and challenged one another regarding their CERs. In this process, the students improved their reasoning skills and their content knowledge. Similarly, in a 2017 study, community college students experienced instruction that was scaffolded and infused with CER strategies. The CER framework was shown to improve student understanding of chemistry concepts during the creation of scientific explanations in an introductory level college chemistry course when given CER activities (Atkinson et al., 2020).

Additionally, over time, students in an introductory environmental science course improved their test scores significantly (Bennett & Gotwals, 2017). Their tests revealed they had more understanding of the presented topics, which was a result of their purposeful examination of the concept. According to McNeil and Krajcik (2008), constructing explanations helps students develop a deeper understanding of science content and improve their ability to write and critique scientific explanations.

Importantly, CER can improve the conceptual learning of students who have linguistic diversity. In a study that involved eighth-grade science students, English language learners (ELL) demonstrated improved conceptual knowledge (Kennedy & Folkes, 2018). The authors of this study concluded that the group discussions were important in supporting the students' development of their conceptual knowledge (which was evident in their reasoning).

The Use of CER Influences Students CER Abilities. Ironically, research suggests that young students can create CERs. Mascaro et al. (2019) revealed that 2- to 4-year-old students possessed the ability to choose relevant evidence to support their claim about the location of a toy in a transparent box. Similarly, a 2018 study showed that early childhood students possess scientific reasoning skills, which was evident by their ability to verbally engage in argumentative processes using reasoning tasks (Koksal-Tuncer & Sodian, 2018). Over time, this ability is lost. Fortunately, students can learn how to use CER again.

As students use CER, evidence suggests that they become better at creating claims, using evidence to support their claims, and connecting reasoning to their claims and evidence. For instance, in one study, students engaged in presenting their claims and refuting these claims using counterarguments (Ecker et al., 2019). The authors found that the more counter claims a student heard, the more the student analyzed their claim, resulting in better claim construction.

The improvement of students' CER abilities is evident in two different studies. A 2017 study of ninth-grade biology students found improvements in CER abilities. As students created and discussed their CERs over 6 weeks, they increased their use of evidence and reasoning when creating a scientific claim (Loch, 2017). Similarly, in Becker (2012), the Process Oriented Guided Inquiry Learning (POGIL) approach, derived from Toulmin's Model of Argumentation, was used in a Physical Chemistry course. In this instructional program, students were asked to justify their claims mathematically. Over time, students used certain levels of evidence when making claims, and they connected mathematical reasoning to their claims.

CER Improves Student Identities, Attitudes, Confidence, and Communication. CER has improved elementary and middle school students' understanding of topics in science. Harshbarger (2016) showed the impact of the CER framework in the elementary science classroom. This study revealed how incorporating the CER framework into a fifth-grade elementary science fair resulted in improved science identity for all students due to their participation in the science fair and an increase in conceptual knowledge. Similarly, Loch (2017) revealed that ninth-grade students in biology used CER to develop arguments in a biology science lab over 6 weeks resulting in the increased use of evidence and reasoning when creating a scientific claim.

Additionally, Atkinson and Pienta (2018) revealed that students in an introductory level college chemistry course improved their attitudes toward chemistry using the CER framework during a series of three in-class chemistry activities involving gas laws, solubility, and buffers during the semester-long course . This study found that allowing more time in class for CER activities led to increased student engagement, understanding of chemistry concepts, and improved scientific explanations.

A study of seventh-grade students showed that students who consistently used the CERC (Claims-Evidence-Reasoning-Conclusion) method in their scientific writing recognized how writing was interconnected and important across all subjects (Grymonpre et al., 2012). As a result, students were able to transfer their writing skills to other subjects.

Kennedy and Folkes (2018) found that students developing claims, evidence, and reasoning during a science laboratory investigation became more confident when discussing laboratory conclusions and engaged in more sophisticated peer discussions. Additionally, this study revealed that ELLs showed conceptual knowledge improvements.

In the study “Scaffolds for Scientific Explanations,” the CER framework was implemented into a middle school science class using United States Historical Data to examine how temperature and precipitation affects tree growth (German, 2018). The CER framework led to an improved ability to communicate through writing. Additionally, McNeill and Krajcik (2011) found that by implementing CER instructional strategies and assessments into the science curriculum students improved their ability to understand scientific topics conceptually and communicate using evidence and claims in their writing.

Group Discussions Are Important in CER Use. Group discussions are a critical component of the CER Framework. During these discussions, learning takes place because of the talking that occurs among group members (Bianchini, 1998). This talk is where the claim, evidence, and reasoning become complete and further develop as knowledge is exchanged through refuting and defending ideas. For instance, Ecker et al. (2019) found that students engaged in presenting their claims and refuting these claims using counterarguments. The authors found that the more counter claims a student heard, the more the student analyzed their claim, resulting in better claim construction.

Similarly, a college-level Physical Chemistry course implemented the POGIL instructional strategy to examine how students develop their reasoning for thermodynamic properties (Becker et al., 2013). This study revealed that when using POGIL whole and small group discussions shaped student norms related to their ability to reason.

A key component associated with improved reasoning (thus, conceptual knowledge) is working in groups. In a college-level Physical Chemistry course, Toulmin's Model of Argumentation was used in weekly lessons (Becker et al., 2013). As the students worked in groups, they reported that their discussions influenced their evolving reasoning ability in the Physical Chemistry course.

In a more nuanced examination of the CERs, Glassner et al. (2005) examined 70 ninth graders' uses of explanation versus evidence while engaging in the argumentation process. They found that students were more likely to generate a complete CER while engaging in the argumentation process (back and for among students).

How Teachers Implement CER Is Important in Student Learning. Teachers see the value of CER in their classrooms. A 2019 study, “Development and Pilot Testing of a Three-Dimensional, Phenomenon-Based Unit That Integrates Evolution and Heredity,” found that 67% of teachers agreed that the CER framework improved their evolution and heredity unit by requiring students to participate actively in the learning process (Homburger et al., 2019). However, the way CERs are presented is important.

McNeill and Krajcik (2009) was a seminal study involving chemistry. This study examined how six teachers and 578 middle school students used two different scaffolding methods (explicit domain-general and context-specific) during a chemistry lesson. This study found that context-specific scaffolds were ideal for written argument support and that both scaffolds (explicit domain-general and context-specific) were needed for an effective science learning environment.

Similarly, Delen and Krajcik (2018) examined how middle school students used their mobile devices to collect data and construct scientific explanations using the CER framework while studying a unit on water quality and plants. They found that teacher collaborations and scaffolding designs played a critical role in an ability to generate and construct scientific explanations.

Summary. CER has been used in many different subjects, which is a testament to its applicability in education. In science, CER has found its use with students who range from preschool to college and subjects that range from English to Science. Its versatility, application among diverse groups, and academic benefits make it a valuable instructional strategy to engage and motivate students in the science classroom. The advantages of the CER Framework have been discussed here in detail. Each advantage details the evidence that shows how CER improves conceptual understanding, science identity, attitudes toward science, confidence, and written communication.

Disadvantages of CER

Although the CER Framework has been shown to have a positive effect on student conceptual knowledge and enhance scientific explanations, some studies have yielded the same positive results. This section will discuss the disadvantages highlighted in the academic literature about CER and its use. This section will discuss the areas of knowledge gains, ELL learners, student difficulties, and teacher use.

CER and the Absence of Student Benefits. Research suggests that CER does not benefit all students equally and, in some cases, no benefit has been found. This result contradicts what most studies suggest about the CER framework. For example, in a 2016 study, 37 sixth-grade students using the CER framework in their general science class showed no improvement in their ability to use evidence or reasoning while completing four different tasks in an argumentative setting (Bilican & Aydeniz, 2016).

Similarly in another study, students participated in a scientific writing skills activity in their seventh-grade science class that evaluated the influence of CER structure and teacher scaffolding techniques in the science classroom. This study revealed that students have difficulty generating claims and effectively using evidence during CER use (Grymonpre' & Solomon, 2012). Although there are contrasting views about the relationship between the use of CER and knowledge gains, the literature highlighting the ineffectiveness of CER is minimal in comparison to the literature that supports the use of CER in the science classroom.

Student Inability to Generate Appropriate Claim, Evidence, and Reasoning. Students often struggle with new CER tasks and CER use when constructing scientific explanations. They cannot generate an appropriate claim, evidence, and reasoning. For example, students used the CER Framework to study endangered species and developed conclusions that were not scientific due to their misinterpretation of data in a study by Nageotte et al. (2018). Novak and Treagust (2018) found that students had problems adjusting their claims when conflicting evidence was presented during small group discussions with peers and teachers. In a different study, researchers found that seventh-grade students who participated in a scientific writing skills activity used to evaluate the structure of CER and scaffolded teaching techniques had difficulty generating claims and using evidence (Grymonpre' & Solomon, 2012).

Walker et al. (2019) found that students did not change their claims or reasoning when shown new evidence that was unsupportive of their claim when engaged in the process of argumentation in a scientific inquiry environment. Additionally, in a community college chemistry lab course, researchers found that students found scientific reasoning to be the most difficult component when using the CER framework (Bennett & Gotwals, 2017). Some common aspects have been identified that many students find challenging and require the attention of educators and researchers if the CER framework is to be effective in the science classroom.

Teacher Challenges During CER Use. Teachers face obstacles while implementing the CER framework in their science curriculum. In McNeill's (2009) seminal study, he found that when teachers oversimplified the CER framework using the argumentation process students decreased their ability to write explanations using appropriate evidence and reasoning. This literature highlights how teacher use of the CER framework can influence student learning and the use of the CER framework in science class. Teacher use of CER is extremely critical during the implementation phase and determines how well students carry out each component of the CER framework.

The Challenges of CER Use by ELLs. ELL students face many different challenges within an academic setting due to language and cultural barriers. In many cases, instructional strategies are implemented to help students who are struggling with language and conceptual topics. CER is one strategy that has been shown to assist ELL students; however, some studies reveal ELL students do not always benefit from the use of CER.

A 2018 study examined the development of student writing over a year using the CER Framework in an eighth-grade science class (Kennedy & Folkes, 2018). This study found that the ELL students struggled with CER statements and became discouraged during the CER process due to language barriers. The ability to write CERs is a useful tool in conceptual understanding. The practice of scientific writing gives students the ability to construct, review, and alter their ideas, which in turn, encourages learning and extends science content knowledge (Abell, 2006; Allen & Rogers, 2015).

Summary. The disadvantages of CER involves student and teacher use of the CER framework. These disadvantages examine the challenges that different student groups and teachers face during CER implementation in the science classroom. Examining the disadvantages of the CER Framework allows science educators to strengthen its overall effectiveness during classroom implementation. The next section will examine the gaps in the literature for CER.

Gaps

Reviewing the literature revealed different aspects of the CER framework that require further research. Some areas were specifically listed, while others were not mentioned or studied. This section will discuss the influence of class structure, argumentation and explanation, teacher, and student perception of CER use, and CER uses in undergraduate chemistry. Each of these aspects of the CER framework needs to be addressed and studied. Finding the answers to these questions will allow the CER framework to be more beneficial for all students.

The Influence of the Physical Classroom Layout on CER Use. The physical structure of the classroom plays a critical role in the implementation of the CER framework and the academic setting. The physical location of students in the classroom can inhibit or encourage peer interactions. Lecture-style seating inhibits student-student and student-teacher interactions. For example, a 2006 literature review by Sampson and Clarke found that future research should examine the correlation that exists between the structural layout of the class and the argumentation process (Sampson & Clark, 2006).

Berland and Reiser (2009) found that students made use of evidence to understand and explain scientific phenomena but failed to engage in the persuasion process due to the challenges that the traditional classroom setting presented. In this study, a biology unit called "What Will Survive?" implemented the Investigating and Questioning Our World Through Science and Technology strategy to examine student use of CER during the construction and defense of scientific explanations.

SCALE-UP (Student-Centered Active Learning Environments for Undergraduate Programs) classrooms have been constructed on college and university campuses to encourage more student-student and student-teacher interactions. In addition, educators have begun to examine strategies that address the challenges the traditional classroom settings present. The CER Framework is an instructional strategy that has been implemented to overcome the social barriers that the traditional classroom presents.

The Importance of Distinguishing Argumentation and Explanation. Argumentation and explanation are often viewed as the same; however, a clear distinction exists. Many students and educators are not able to distinguish between argumentation and explanation.
Flaig (2015) discussed the need to clarify the difference between the scientific practices of argumentation and explanation to avoid confusion (see also Osborne & Patterson, 2012).
This article found that during professional development sessions the two

terms, argumentation, and explanation, were used interchangeably. The improper use of the two terms poses a major challenge for teachers and students. This confusion between argumentation and explanation inhibits the proper implementation of each instructional as well as its use by students and teachers.

The Relevance of Teacher and Student Perception of CER Use. Little research has investigated the teacher and student perception of the CER framework. The absence of this view is particularly important in understanding how CER can be effectively used in the science classroom. The perception of the teacher and student influences how an instructional strategy impacts the classroom.

Teacher and student views about the CER framework play a key role in its implementation and use in the science classroom. Myers and Rocca (2001) found that the instructor's behavior played a key role in the conceptual outcomes of students (see also Sorensen & Christophel, 1992). Similarly, a 2010 study by Kaya et al. revealed that student perception of CER played a critical role in the learning and achievement that took place in the science classroom (see also Koballa et al., 1990). These studies reveal the importance of teacher and student perception about the CER Framework.

The Lack of CER Use in Undergraduate Chemistry. A review of the CER literature revealed minimal research examining the CER framework at the undergraduate level, specifically in Chemistry. However, some studies examined the CER framework at the elementary, middle, and secondary levels across different subjects and age groups. The studies that follow highlight the current research about science and the CER framework at elementary, middle, and high school levels.

McNeill and Krajcik's (2009) seminal study examining a middle school chemistry curriculum found that using scaffolds during the CER process supported written arguments. In addition, Harshbarger (2016) found that conceptual knowledge increased using the CER framework in fifth-grade elementary school science class. These studies provide insight into how the CER framework is used in science classrooms on different academic levels.

Summary. The use of CER at the college level in general chemistry is missing. The CER framework is an important instructional strategy due to the high number of failures and withdrawals from general chemistry at the undergraduate level. Failure or withdrawing from an introductory science course can cause students to change their career paths in science (Burdge & Daubenmire, 2001; Jones, 1994; Seymour, 1992). Many students leave the field of science because of their lack of success in general chemistry, and in many cases, they look to pursue degrees in fields other than science. Because chemistry is a gateway course that most first-year science majors take, educators must implement the best instructional practices to ensure student success and retention. Research studies suggest that the use of the CER framework could be a solution to this problem.

Generative Learning Theory

One concern of educators is to improve student learning (Ritchie & Volkl, 2000). To address this concern, educators implement instructional strategies that enhance instruction within the classroom. These strategies provide students with the opportunity to engage actively in the learning process. These strategies are guided by different learning theories. One important theory in science education is that learning is a generative process (see Fiorella & Mayer, 2015). In this theory, students examine new knowledge and combine new knowledge with existing knowledge, which has relationships created between new and prior knowledge (Ritchie & Volkl, 2000).

Generative learning requires students to participate actively in the learning process by selecting, organizing, and integrating new and prior knowledge (Klingenberg et al., 2020). According to Fiorella and Mayer (2015), generative learning is an active process where students make sense of new and prior knowledge through the cognitive organization and integration of new knowledge.

A long-standing model of generative learning in science education was developed by Wittrock. Wittrock's model of generative learning states that meaningful learning has four components: (a) Generation: connections the learner builds between new and prior knowledge, (b) Motivation: the willingness of the learner to invest effort toward understanding new knowledge, (c) Attention: directing generative processes to new and prior knowledge, and (d) Memory: the learner's new knowledge experience and beliefs (Fiorella & Mayer, 2015). Basically, when students are motivated, they attend to specific areas of knowledge and make connections between these knowledge areas. When the knowledge is assimilated, it is stored in their memory.

Generative learning can occur through learning strategies such as summarizing, mapping, drawing, imagining, self-testing, self-explaining, enacting, and teaching (Klingenberg et al., 2020; see also Fiorella & Mayer, 2015). These processes can be supported through different types of instructional strategies. When students engage in these types of activities, which are aligned with generative learning, students improve their understanding of the content (Brod, 2020).

However, this improvement is not the same for all students. In a 2000 study conducted by Ritchie and Volkl, 80 sixth-grade science students use two generative learning strategies – concept mapping or lab experiment – to determine their overall effectiveness. The students were given pre- and posttests to evaluate which strategy was most effective when working individually or as a group. The students were randomly assigned to groups or worked individually. The findings of the study revealed that students who used the concept maps had higher scores than did those who began with laboratory experiments. Similarly, Brod's (2020) study revealed that six generative learning strategies (concept mapping, explaining, predicting, questioning, testing, and drawing) had varying levels of effectiveness when it came to learning among university and younger students. The differences in effectiveness were correlated to the prior knowledge of the students. Clearly, the outcomes of generative learning are positive but varied.

In summary, this study will use the generative learning theory to address the learning of students engaged in a CER activity. In general, generative learning strategies like CER have been effective at the university level (Brod, 2020), because students possess prior knowledge that can be activated and connected to new knowledge.

CHAPTER 3

METHODS

This chapter begins with an overview of this study's research approach, followed by an expanded discussion of the context of the study and the activities in the study. A description of the participants will follow. The data collection process and the analysis of the data during the research process is the majority of the chapter. Finally, the limitations of this research will be stated.

Overview

This study took place in a semester course, and the research design emerged from prior studies that researchers conducted. The study involved an intervention, which was the use of a CER with students in the class. The data were analyzed using qualitative and quantitative approaches. The qualitative data were the basis for this study. The use of CER, which was the intervention, occurred three times over the semester. Each CER activity was presented as a research question that the students were to answer as a claim. The students were given data as evidence to interpret and to develop the conceptions that were central to the activity. During the first activity, students were explicitly instructed on the scientific practice of constructing explanations using the CER framework (as defined by Sampson et al., 2015).

The students were instructed to complete their CER document as homework before coming to class. Students then came to class with a completed individual CER document (worksheet for students to complete as an individual and a group during each CER activity). The students worked in their small groups to complete a group CER document in class. A whole group discussion followed where the researchers and course instructor discussed the CER activity with the class. In this study, three activities were developed using the CER framework, was focused on (a) gas laws-CER1, (b) solubility rules-CER2, and (c) buffering capacity-CER3.

The qualitative data consisted of the CERs and the audio recordings of the groups, which occurred during the third CER. The CERs were analyzed for their construction, while the audiotapes were analyzed to understand the explanation process of the small groups of students. These data were analyzed inductively with a rubric and a comparison process using discourse analysis. Quantitative data were collected using Bauer's (2008) Attitudes Toward the Subject of Chemistry Inventory, Chemistry Self Concept Inventory (Bauer, 2005), and Mulford's Chemistry Concept Inventory (Mulford & Robinson, 2002). However, these data were not used in this study. It is described to ensure that the data collection process is understood.

In addressing the research questions of how knowledge is transferred from an individual to a group using the CER framework, the research team studied participants in an undergraduate introductory chemistry course. The students (n = 14) in this study formed six groups. Two groups were White and Black females, two groups were White males, one group was Black males, and one group was White females.

Procedure

During each of the activities, the students completed their CER document individually as homework. On the day of the CER activity, students joined their small group to complete a group CER document. They were encouraged to talk to one another and work through any discrepancies to come to a consensus as a small group, which consisted of two to five students. The students were given time to write out their thoughts and conclusions to generate a group

CER. Upon completion of the group CER document, a whole group discussion was conducted by the researchers and course instructor.

The small groups were self-selected groups that students formed during the first week of the course. Students remained in these small groups for the entire semester. These small groups were a component of the course and were implemented to encourage peer interactions. The research team focused on the last CER because the interactions among the students were established by this time.

To understand the influence of status, race, and gender, researchers observed and collected notes on students' interactions and group dynamics throughout the semester. As a result of their observations, the researchers selected specific small groups to be audio-recorded during the final CER lesson of the semester. The small groups were chosen based on diversity, peer interactions, and group discussions.

During the final CER lesson, the researchers collected audio recordings and made participant observations of selected small groups. These observations followed recommendations by Bogdan and Biklen (2007) and recorded group discussions and peer interactions of these selected groups. The audio recordings lasted the entire class, with an audio recording device place in the center of each group.

Additionally, student surveys were given to all students during the final CER activity. These surveys required the students to indicate their gender and race, to note who in the group were their friends, who they worked within the group, and who they considered to be the "A" students in the groups (perceived status). The audio recorders, CER documents, and student surveys were collected at the end of the class for analysis.

Context

This study took place at a large, research university located in the southeastern United States in an introductory chemistry course. The university is a land and sea-grant institution with 17 schools and colleges with an enrollment of 38,652 and a population consisting of 67% White, 10% Asian, 8% Black, 6% Hispanic, and 9% other demographic groups. This university is the flagship school for the state and described as a predominantly White institution.

The course was a 4-credit-hour class designed to prepare students for first-semester general chemistry. This course was referred to as a “drop back” course. Students could enroll in the course by registering at the beginning of the semester or dropping back into the course after enrolling in first-semester general chemistry and performing poorly on the first exam. This course was design to address the failure rates and the number of withdrawals from the university’s first-semester general chemistry course.

This chemistry course was taught in a student-centered active learning environment with an upside-down pedagogies (SCALE-UP) class with one instructor and three peer-learning assistants. The SCALE-UP pedagogy allowed the instructor to replace traditional lecturing with activity-based classroom instruction (Beichner et al., 2007). The SCALE-UP class contained round tables that could accommodate up to nine people. Each round table was equipped with three computers and movable chairs. Large screens were located throughout the class to present activities. The classroom had a maximum capacity of 72 and was designed to promote student-student and instructor-student interactions.

CER Activity

There were three CER activities in this course (see Table 1), and the third CER activity was the focus of this study. The CER activities consisted of a research question and data about chemistry phenomena. They required students to develop a claim, support the claim using evidence, and provide their reasoning that connected the evidence to the claim. Students completed the CER activity individually as a homework assignment and in class as a small group for each of the three activities.

The small groups were self-selected and consisted of two to four students who worked together throughout the semester. The students were encouraged to talk to one another and work through any discrepancies to come to a consensus during the small group discussion. The consensus of the group discussion resulted in the completion of a group CER document.

The CER activities were created as a single PowerPoint electronic slide. The CER activities were placed online, prior to class, using the Qualtrics Survey System. Qualtrics is a professional survey platform that is used for surveys and has become popular for noninteractive experiments (Molnar, 2019). In class, the CER slide was broadcast electronically on the LED monitors in the class using an online link generated by Qualtrics.

The chemistry assessments and CER activities had the content validated by expert-level chemists and science educators. The chemistry phenomena covered in the assessments and CER activities were gas laws, solubility, and buffers, in that order. The CER activities were field-tested during a pilot study and revised after careful evaluation of student responses by the research team. Each activity is described in Table 1 by topic and scientific phenomena.

The third CER, which is the basis of this study, focused on buffers. The guiding question was, “Use the data below and what you know about buffers to explain why scientists have predicted that marine life will vanish in the future? This means we may not have fresh seafood to eat. Make a claim, support that claim with evidence from the data, and provide your reasoning.”

This CER activity used the process of ocean acidification to examine the chemistry concept of buffers. In this activity, the students were asked to use four data tables that described carbon dioxide and pH levels, oceanwater pH trends, pH range of marine life, and carbon dioxide reactions in the ocean to develop a claim that answered the research question. Using these tables, the students were asked to generate a CER using all the data.

Table 1

CER Activities by Topic and Scientific Phenomena

Activity	Chemistry Topic	Science Phenomena
CER #1	Gas Laws	Causal Patterns in Air Pressure
CER #2	Solubility	Water Hardness
CER #3	Buffers	Ocean Acidification

Participants

This study took place during one semester of the course. The students were given an overview of the research project a week before the first CER in the course. Students then enrolled in the study by signing a form that gave their informed consent. This form was reviewed by the university's Internal Review Board informed consent process. In the form, students agreed to be audio recorded as well as interviewed, if needed. The chemistry course consisted of 49 students, who were 67% female and 33% male. Among the students, 73% were White, 16% Black, and 11% Asian. Of these 49 students, 46% enrolled in the course at the beginning of the semester while 54% registered after taking their first general chemistry exam. However, the data for this study was collected by examining 14 of the 49 students in the class, who were 57% female and 43% male, 57% White, 36% Black, and 7% Asian.

The 14 participants made six groups, as described previously. The groups were chosen by the researchers based on diversity, student engagement, and the small group discussions that took place during the previous CER activities. The selection process aligns with unique sampling, which is based upon the attributes of the sample related to the phenomena of interest (Merriam, 2009).

Data Collection

Overview

The data collected in this study came from the third and final CER activity. By selecting the third activity, the researchers assumed that group members had established some relationship norms and connections to one another due to working together throughout the semester. These routines and familiarity as group members over the semester are important because of their contribution to the validity of the research findings of this study.

During the third activity, students each completed an individual CER document before coming to class as homework and then worked in a small group to generate a group CER document. The small group discussions were audio-recorded so the researchers could examine the peer interactions and exchange of ideas that took place during the group CER construction. The students were given a student survey to complete, which was followed by a whole group discussion. The survey reported demographic information about the students and their group members.

The CER documents, audio recordings, and student surveys are the three sources of data in this study. Each source of data will be described in the following sections. After discussing the different data sources, the validity and reliability of the data collection process will be addressed.

CER Document

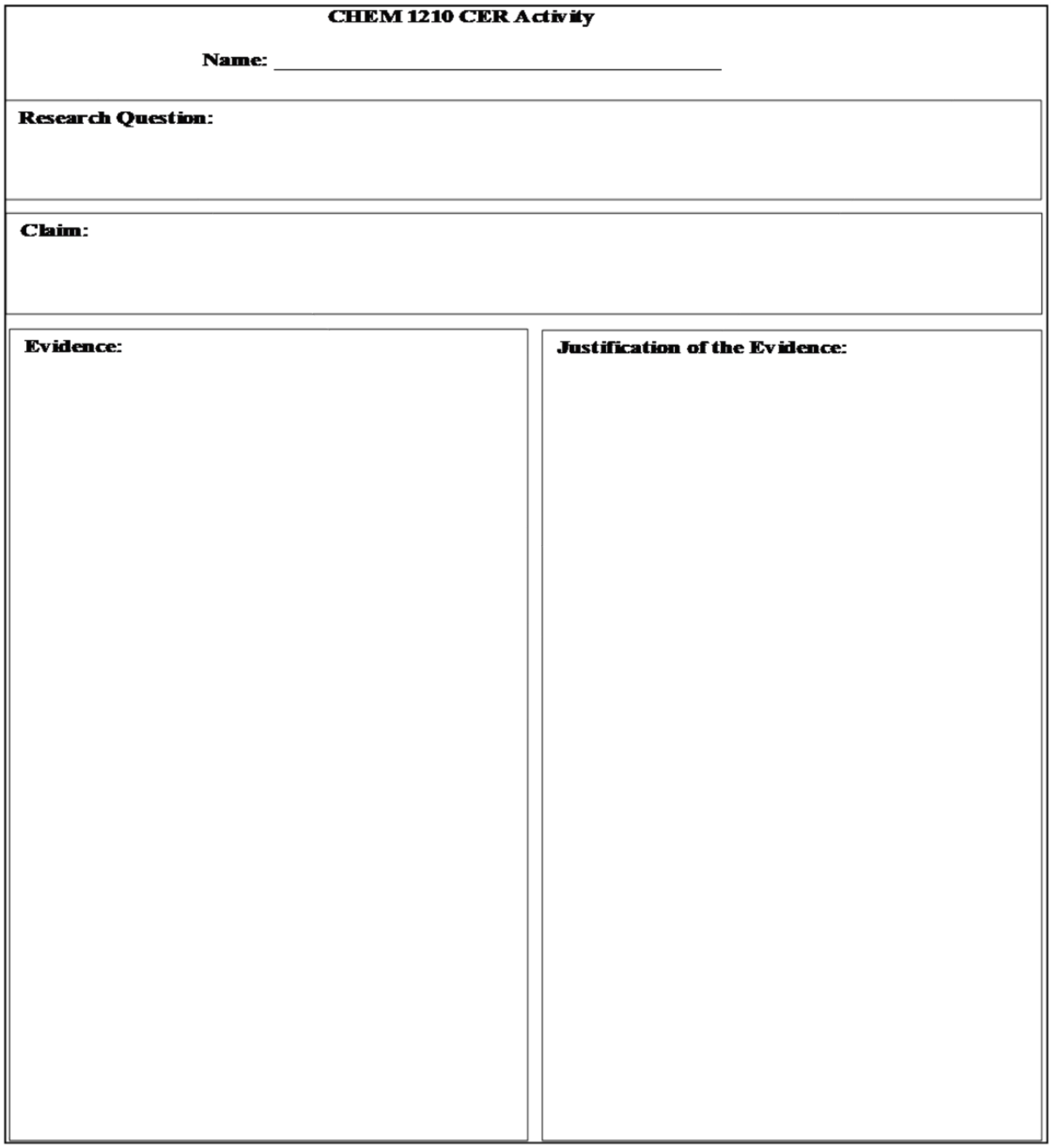
The researchers distributed the CER document to the students as a homework assignment to be completed before coming to class on the day of the CER activity. This distribution took place during the class meeting before the CER activity. During the distribution of the CER document, the students were given a brief overview of the activity and the online link to access the CER activity. Again, the students were instructed to complete the CER document before coming to the next class session, which was available through a Qualtrix link. Students may have had questions about the completing the activity. While the instructors could help the students through email, the students were encouraged to do the best they could with the information that they were given through the link and in class.

On the day of the CER activity, students were asked to take out their CER documents and discuss their responses with their small group members. By working together, a group CER document was created that reflected a group consensus. Upon completion of the group CER document, the individual and small group CER documents were collected by the research team.

The CER document was designed by the team members based upon the work of Sampson et al. (2015, p. 8). The document contained an area to write a claim, the evidence, and the reasoning. The students also put their name on the document, so it could be traced back to a group if it became separated from the other forms. This document was pilot tested in previous semesters. To ease the confusion of collecting multiple sheets of data that had the same outline, the sheets were color-coded. The individual CER documents were blue, while the group CER documents were yellow. Figure 1 is an example of the CER documents.

Figure 1

Example of a CER Document



CHEM 1210 CER Activity

Name: ____

Research Question:

Claim:

Evidence:

Justification of the Evidence:

Audio Recordings

To collect the data from the small group discussions, selected small groups were audio-recorded during the third CER activity. These recordings were important to the study because by the time of the third CER activity the groups had settled into their collaborative processes and established their group norms. The groups selected to be recorded were based on their composition, level of engagement, and peer interactions during the first two CER activities. The researchers were focused on selecting groups that could help shed light on the study's research questions, which focused on CER formation and group interactions.

A team meeting was conducted where various aspects were discussed about the different groups; for example, the way group members worked with one another, prior results on their CERs, and the diversity of group members. The final selection of small groups to audio record was reached by consensus among the research team members, which included graduate students and a faculty member.

A digital audio recorder was placed in the middle of each group to record their interactions during the group CER construction. The appropriate placement of the audio recorder was determined during earlier CER activities by placing the audio recorders in different locations on the group table.

In the final CER, the audio recorders were placed in the selected location. They started at the beginning of the activity and were turned off at the end of the activity. They were collected from the groups, downloaded, labeled, and stored in a secure location for transcription and analysis.

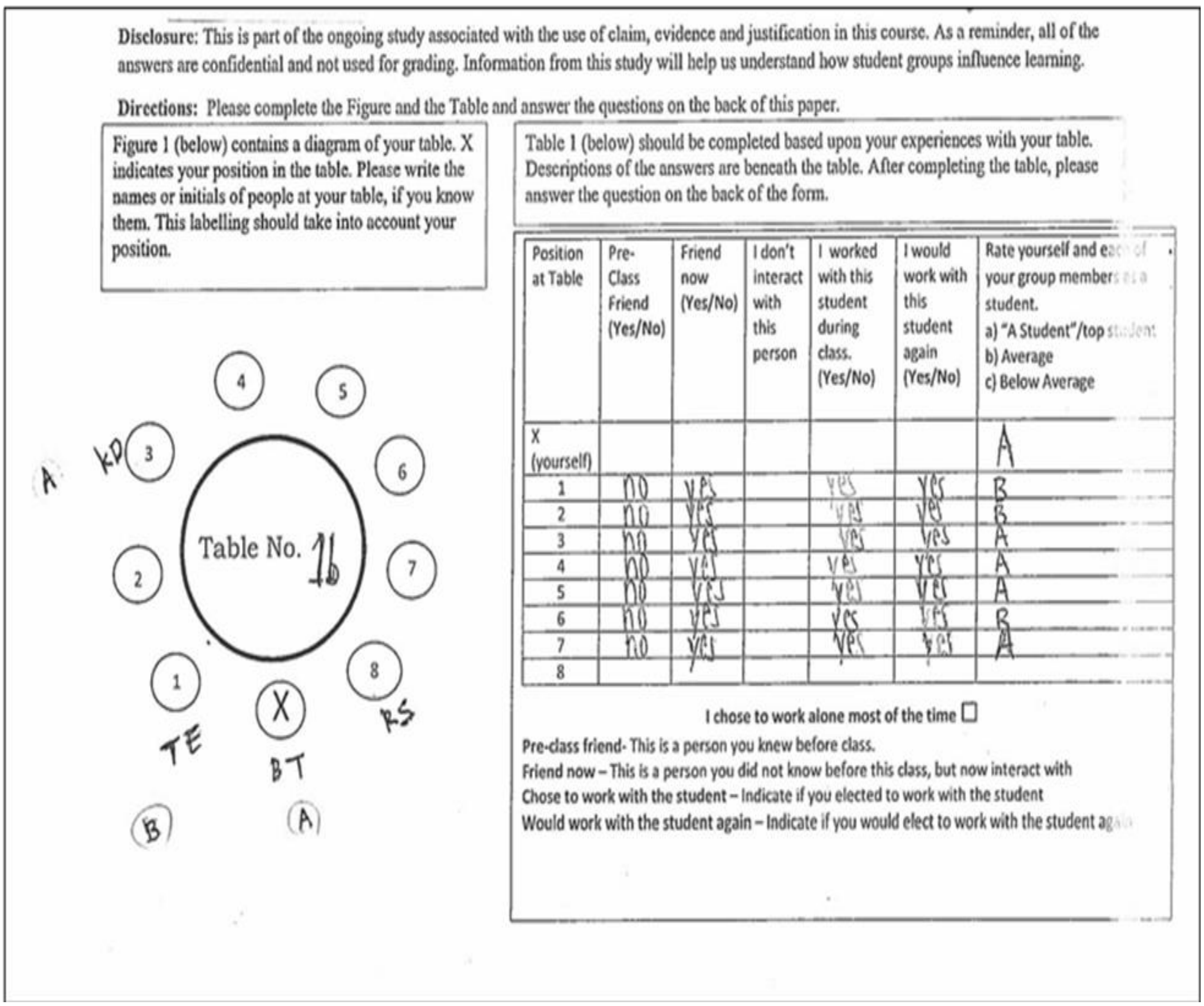
Student Surveys

Each student in the class was provided with a student survey (see Figure 2). The student surveys were developed by the research team and designed to collect demographic information about the participants (race and gender) and their perception of themselves and their group members as chemistry students (perceived status). Additionally, the students reported their location in the group (location in which they sat); their perceptions of their peers as (a) "A"

Student, (b) Average Student, or (c) Below Average Student; if they worked with the fellow students outside of class; if they were friends with the other students in their group; and if they would work with their peers again. The student surveys were given during the third CER activity. The surveys were collected soon after the students completed them, so that students would not know their peers' perceptions of them.

Figure 2

Example of a Completed Student Survey



Disclosure: This is part of the ongoing study associated with the use of claim, evidence and justification in this course. As a reminder, all of the answers are confidential and not used for grading. Information from this study will help us understand how student groups influence learning.

Directions: Please complete the Figure and the Table and answer the questions on the back of this paper.

Figure 1 (below) contains a diagram of your table. X indicates your position in the table. Please write the names or initials of people at your table, if you know them. This labelling should take into account your position.

Table No. 16

Table 1 (below) should be completed based upon your experiences with your table. Descriptions of the answers are beneath the table. After completing the table, please answer the question on the back of the form.

Position at Table	Pre-Class Friend (Yes/No)	Friend now (Yes/No)	I don't interact with this person	I worked with this student during class. (Yes/No)	I would work with this student again (Yes/No)	Rate yourself and each of your group members as a student. a) "A Student"/top student b) Average c) Below Average
X (yourself)						A
1	no	yes		yes	yes	B
2	no	yes		yes	yes	B
3	no	yes		yes	yes	A
4	no	yes		yes	yes	A
5	no	yes		yes	yes	A
6	no	yes		yes	yes	B
7	no	yes		yes	yes	A
8						

I chose to work alone most of the time ☐

Pre-class friend- This is a person you knew before class.
Friend now – This is a person you did not know before this class, but now interact with
Chose to work with the student – Indicate if you elected to work with the student
Would work with the student again – Indicate if you would elect to work with the student again

Validity of the Data Collection Process

According to Johnson (1997), valid qualitative research is plausible, credible, and trustworthy. Various procedures have been developed to ensure trustworthiness and validity while conducting research (Jones & Donmoyer, 2021). The researchers of this study ensured study validity by triangulating the data collecting methods and data sources and by using multiple investigators and extended fieldwork (Johnson, 1997).

In this study, the data sources were triangulated by the CER documents, audio recordings, and student surveys. Additionally, the use of multiple investigators addressed the problem of subjectivity by having more than one researcher examining the phenomena. The extended fieldwork further ensured the presence of validity, which allowed the researchers to document the study environment and consistency of student work over a semester.

Data Analysis Process

The data were analyzed in different steps. In the first step, the individual and small group CER documents were evaluated by using an adapted CER rubric. The rubric focused on the accuracy and the comprehensive nature of the students' constructed CER. These documents were further analyzed for the quality and the flow of ideas from individual to small group.

In the second step, the researchers listened to the audio recording to analyze the discourse patterns within the groups. This analysis involved determining who was speaking and how the language patterns were contributing to the creation of the CER.

In the third step, the demographic data and the analyzed data were compared, contrasted, and examined to determine the different trends and patterns. The resulting data were placed into a visual display that represented how the students interacted with one another. Table 2 describes the diverse ways data were analyzed in this study.

Table 2

Summary of the Data, Focus of the Analysis, and Analysis Tool or Process

Data	Focus of the Analysis	Analysis Tool or Process
CER Documents	Chemistry content	Scoring using an adapted rubric
	Description of the CER content	Explanation or description orientation/ Flow of discourse framework/ Level
	Transfer of knowledge	Examination of the CER from individual to small group
Audio Recordings	Dialogic/Authoritative talk	Science discourse framework
Student Surveys	Race/Gender/Perceived Status	Examination of the CER data

Evaluation of the CER Documents

Before scoring the CERs, the researchers constructed a CER rubric. The CER rubric (Figure 3) was developed by the research team and drew upon the work of Sampson et al. (2015). To develop the rubric, the team first looked through the literature to find rubrics that could be used to evaluate the CER documents. The team located general rubrics but none specific enough to evaluate the CERs that were generated in the class. The team then developed a rubric that aligned with this study but drew upon the general rubrics.

To develop the rubric, the team followed some of the protocols about rubric development and use (Luft, 1998). To begin, the researchers identified the key areas to evaluate and then discussed the classification of low- and high-level performance. The middle levels of performance were added following the low-and high-level performance. The rubrics were tested on a few student CERs from a prior class and revised accordingly. After careful evaluation and additional team discussions, a consensus was reached about rubric use. The rubric accounted for the accuracy of the science content and the comprehensive nature of the individual and small group CERs. The final CER rubric rated individual and small group CERs on a scale from 0 to 4.

The CER documents were collected by one researcher, and they were sorted into two groups: individual CERs and group CERs. Each individual CER document was evaluated by two researchers. Prior to scoring the CERs individually, the researchers practiced their scoring of CERs with the rubric. The researchers had to have a high interrater reliability of 90% before they could score independently. When this rate was achieved after a few sessions, the researchers scored the CERs independently. After the independent scoring, the researchers met in pairs to discuss their evaluation of the scores they had for each of the CER documents. If the scores were inconsistent, the researchers brought in a third scorer and came to a consensus about the CER scores. All scores represent a consensus, which documented the scores for the individual and the group. The scored CER documents were placed in an Excel spreadsheet, which noted the individual, the group, and the subsequent scores.

Figure 3

CER Scoring Rubric

	Rubric Score				
Explanation Component	4	3	2	1	0
Claim – a statement that answers the original question	Scientifically accurate and addresses the phenomena Sufficient in acknowledging the critical factors	Scientifically accurate and addresses the phenomena Partially sufficient in that more (or fewer) critical factors are provided than are needed	Partially scientifically accurate (broadly or indirectly addresses the phenomena) Partially sufficient in that more (or fewer) critical factors are provided than are needed	Not scientifically accurate (does not address the phenomena) Does not adequately answer the question NOTE: Descriptive, but does not address factors.	No claim provided
Evidence A (Claim score of 4 or 3) – data and/or patterns, trends, and/or inferences from the data that justify the claim	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 (not required)	The data are scientifically appropriate to support the claim. The data are sufficient and convincing, but additional data could be provided. NOTE: Comparison is made (Deflategate)	The data relate broadly or indirectly to the claim. The data is not sufficient and additional data should be provided.	There is some evidence provided, but it is not logically linked to the claim nor is it scientifically appropriate NOTE: (random things that are not relevant OR scientifically correct but not related to the concept)	No evidence provided

Figure 3 (con't)

CER Scoring Rubric

Evidence B (Claim score of 2 or 1)	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 (not required)	The data are scientifically appropriate to support the claim. The data are sufficient and convincing, but additional data could be provided. NOTE: Comparison is made (Deflategate)	The data relate broadly or indirectly to the claim. The data is not sufficient and additional data should be provided.	There is some evidence provided, but it is not logically linked to the claim nor is it scientifically appropriate NOTE: (random things that are not relevant OR scientifically correct but not related to the concept)	No evidence provided
Reasoning A (Claim score of 4 or 3) -- uses scientific ideas to explain how or why the evidence supports the claims	Reasoning clearly links all 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.	Reasoning clearly links all the evidence to the claim. Includes related science ideas and may make some connection The scientific ideas are accurate but are not discussed comprehensively.	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. NOTE: "Talking around" scientific ideas	Few and no links of evidence to the claim The discussion of key ideas is limited or absent. NOTE: Repeats evidence	No reasoning provided

Figure 3 (con't)

CER Scoring Rubric

Reasoning B (Claim score of 2 or 1)	Reasoning links all 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.	Reasoning clearly links all the evidence to the claim. Includes related science ideas/ make some connection The scientific ideas are accurate but are not discussed comprehensively.	Reasoning links some of the evidence to the claim. Includes related science ideas/ may not make a direct or complete connection The scientific ideas are not accurate or may not be discussed comprehensively.	Few and no links of evidence to the claim The discussion of key ideas is limited or absent. NOTE: Repeats evidence	No reasoning provided

CER Document Analysis-Chemistry Content. The chemistry content was analyzed using the CER rubric. The rubric used a rating scale of 0-4 to characterize the chemistry content. For example, a rating score of 0 means no scientific accuracy and the claim does not answer the question. A claim with a score of 4 is scientifically correct, addresses the chemistry phenomena, and addresses the critical scientific factors.

The CER documents for the individual and small groups were evaluated separately by each member of the research team. Before they evaluated the documents, the team members reviewed the rubric and practiced scoring several CER documents together. Once each CER document was evaluated and recorded the research team discussed each individual and small group CER. The team members came to a consensus regarding the CER documents score (as recommended by Herrera et al., 1996). to achieve interrater reliability of 90% agreement.

CER Document Analysis-Explanation Type. The CER explanation type was categorized as a description or explanation. The Flow of Discourse Framework was used to guide this analysis (Hoon & Hart, 2007). The explanation uses scientific theories, models, and mechanisms to describe phenomena (Schalk et al., 2013). Another way to consider the explanation type is that description is the “what” and explanation is the “why” (Bergmann, 1957, p. 79; Reese,1999). The CERs were labeled as an explanation if theoretical and conceptual knowledge made up more than half of the written CER. In contrast, if evidence and data made up more than half of the written CER, then the CER was categorized as description. One researcher reviewed the CERs and assigned an explanation type.

CER Document Analysis-Explanation Level. The CER explanation level was described as High (Hi), Moderate (Mo), or Low (Lo). Explanation level was determined by the amount of theory versus evidence used throughout the written CER. Each statement was reviewed for the quality of theory and evidence. This category is different from the explanation type because it looks at how the theory or conceptual topics were used in comparison to the amount of evidence while generating a CER.

If the CER used theoretical knowledge (reasoning) that was appropriate for the problem, then the explanation level was categorized as high. A CER having theoretical knowledge that somewhat addressed the problem was classified as moderate, while a CER that had theoretical and conceptual knowledge that did not really address the CER was rated low. One researcher reviewed the CERs and assigned an explanation level.

CER Documents Analysis-Knowledge Transfer. The transfer of chemistry knowledge during small group discussions was analyzed by comparing the individual CER document to the small group CER documents. The individual CERs were scored and place in their representative groups.

The small group CER documents were then compared with each group member's CER document using comparative analysis (Miles et al., 2014). This involved looking for words or descriptions that were transferred from individual document to the group document. Key words and statements were noted and traced from individual to group documents. The focus was on how the terms and statements passed through group discussion.

If one idea was prominent from individual to group CER, that idea was labeled as dominant. If a final idea was connected to different individual documents, the idea was viewed as blended. Within each document were varying degrees of blended and dominant ideas. The final determination of the degree of blended or dominant was based upon the amount of blended or dominant notations. This analysis was completed by two researchers.

Analysis of the Audio Recordings

The audio recordings were an important part of this analysis. The audio recordings also transcribed for further analysis of the group discussions. One researcher listened to and read the audio recordings to analyze how ideas were presented and discussed and how ideas were passed through a group. These interactions were analyzed using the Science Classroom Discourse Framework (Scott et al., 2006).

Audio Recordings-Science Classroom Discourse Framework. The Science Classroom Discourse framework was used to describe the student-student communicative approach. This framework was developed by Mortimer and Scott (2003) based on their work in secondary science classrooms with students. They noted that students had different discourse patterns, which contributed to their understanding.

The Science Classroom Discourse Framework focuses on student-to-student and teacher-to-student interactions during classroom lessons. The dialogic talk considers the views of others about a scientific topic, while the authoritative talk is only one view or perspective (Sickel et al., 2013). Dialogic talk represents interactive conversations, where the members of a small group are engaged in meaningful discussions and all of their perspectives are considered by the group. Authoritative talk is a conversation that is driven by one group member's perspective or view and not that of the group (Aguiar et al., 2010).

One researcher was responsible for this analysis. Originally, the researcher listened to the audio recording, but then transcribed the recordings to better understand the discourse. As the researcher listened to the audio file, the type of student interactions was noted for the different students; for instance, if a student made a dialogic statement, which would be two students discussing the CER activity. Following is an example of two students discussing their claims during the third CER activity:

> Student 1: "So the claim is the buffering capacity of ocean water has decreased with time as carbon dioxide in the atmosphere has increased."
>
> Student 2: "I just said the buffering capacity has decreased with time because with time because I did not use evidence."
>
> Student 1: "So our evidence, CO_2 came from the chart on the left."

In this discussion, Student 1 had a better claim than Student 2 because of her use of evidence. Student 2 was directed to the chart on the left that had data about carbon dioxide levels. In addition, Student 1 was able to show Student 2 how to use evidence to create a better claim. In this dialogic discussion, each person would be categorized as dialogic.

All conversations were noted as either authoritative or dialogic. One researcher was responsible for transcribing and reviewing the audio tapes to determine the type of discourse that occurred in the group.

Audio Recordings-Transcription of the Audio. One researcher was responsible for the transcription of the audio recordings. The audio recordings were transcribed using Otter.ai transcribing software. The transcripts provided textual data that could be studied easily by the researcher. The textual data also provided a document that could be used to contemplate the group dynamics and the interaction of group members. It was easier in a transcript to see an idea carry forward over time.

Student Surveys and Analysis

Student Surveys. Information regarding race, gender, and perceived status was collected. The demographic and perception data were connected to the discourse as well as the individual and group CER documents. Groups were viewed in terms of their ideas, the quality of the discourse, and their race, gender, and status. The data were put into a case display that explored the different relationships (Miles et al., 2014). This type of display has the individuals grouped by working group and notes the qualities that have been previously assessed. The researchers examined each group looking for trends that may explain how the claims emerged. These data were translated into displays and revised accordingly.

Student Survey Analysis. The participants' race, gender, and perceived status were collected and recorded from the questions on the student survey. This information was placed alongside the CER and audio analysis in the case. The student surveys for this study were important in considering who was speaking, whose ideas were translated through the CER, and who the students were in terms of race, gender, and data. These analyses provided context for the resulting CER analysis.

Graphical Representation of the Analysis

Combined In- and Cross- case Analysis. All the data were placed into an in-case display, which allowed for the explorations of the different relationships within the case (as recommended in Miles et al., 2014). Groups were viewed in terms of their ideas (CERs), the quality of the discourse (audio recordings), transfer of knowledge, and their race, gender, and status.

Each group was a case. The individuals within the case were compared to one another, and a memo was written about each case. Each case was then compared to other cases to look for similarities, differences, or patterns. In this process, disconfirming evidence (Miles et al., 2014) was examined to strengthen the emerging finding. This evidence could challenge the emerging ideas. When disconfirming evidence was noted, the emerging idea was either revised or eliminated.

Two researchers identified emerging themes and revised them accordingly to best represent the evidence. The resulting relationships and themes of the analysis are represented graphically in the next chapter. Each graphical representation is composed of a pie graph with word descriptions, color variations, pattern gradients, and a legend that describes each component of the chart.

Display - Pie Graph. The pie graph represents the individual explanation (inner pie) and group explanation (outer pie). The pie graph is a combination of two graphs that represents the individual members of a group and the group. Each pie graph shows the explanation level, explanation type, and perceived status of individual group members. The group pie graph (outer pie) shows the group explanation type and group explanation level. The explanation type and level are described by the pattern gradient and color variation of the pie graphs.

Display - Legend. The legend describes the explanation type, explanation level, and perceived status of each group member and the group. The explanation type is characterized as Description (D) and Explanation (E). The explanation level and perceived status are classified as Low (Lo), Moderate (Mo), and High (Hi). The legend defines the meaning of each item that graphically depicts the individual and group explanation.

Validity of the Data Analysis

Validity in research is thought of as dependability, authenticity, rigor, and soundness (Fitzpatrick, 2019). In this study, dependability occurred in the enactment of data collection protocols. They were similar throughout the semester. Authenticity occurred in the collection of data. The data came from the work of the students. Rigor involved the collection of the data at different time points to capture the change. Soundness in the data collection occurred as data were tracked for completeness. Each group had a data source.

In addition, the data in this study were triangulated by different researchers and data sources. According to Fitzpatrick (2019), the process of triangulation is the most recognized strategy to promote validity in research. Triangulation of the data increases the understanding of research questions (Hayashi & Hoppen, 2019). Triangulation occurred by having multiple team members evaluate the data (e.g., CER documents), which sought to eliminate bias in research and added validity (Merriam, 2009).

In addition, the data collection process of this study occurred at the end of an extended period. This approach resulted in the participants being comfortable in the process and sharing more freely by the time the data for this study were collected. Finally, the implementation of the CER activities followed the same steps each time allowing the participants to establish group norms and relationships, thus further promoting validity (Johnson, 1997).

Limitations to this Study

The major limitations of this study were the number of students, the group diversity, and the self-selection of small groups by the students. Not all of the groups were used in this study. This was because not all of the groups could contribute to the understanding of the questions. In addition, the groups were not as diverse (based on race and gender) as I had hoped to have at the start of the study. This lack of diversity in the small groups was the result of students self-selecting their group members, which happened during the first week of the semester. The lack of group diversity did not provide an extensive way in which to ensure the outcomes of the study. Future studies will control the race and gender of group members. Despite this condition, I still have confidence in the conclusions of the study because the groups have some diversity.

CHAPTER 4

RESULTS

This chapter consists of the data analysis from this study. It will begin with an overview of the study followed by the study's research questions. Next, the findings are described from the CER documents. These CER document findings examine the chemistry content and the type and level of the explanation among individuals and groups. Then, the results are shared from the audio recordings and student surveys. A summary and graphical representation of each student group are then shared to bring the data together. In closing the chapter, a summary of the research findings will be discussed.

Overview of the study

This study the construction of CERs in an introductory chemistry course and how the composition of the student group (race, gender, and perceived status) may have influenced the CER construction. The students engaged in three CER activities over the course of a semester. During the CER activities, students completed an individual and small group CER which was followed by a whole group discussion.

During the third CER activity, selected small groups were audio-recorded to document the interactions among the group members. In addition, the students completed student surveys about themselves and their group members. The CER documents and audio recordings were collected at the end of the CER activity. The collected CER documents were analyzed to determine the quality of the chemistry content in the CERs, the transfer of knowledge in the

CER, the type of explanations among group members, and the quality of the discussion in the groups.

The CER rubric was used to evaluate the CER documents. The scoring of the CER was done for individual groups members as well as the group. The audio recordings were evaluated to understand how the discourse related to the CER construction. The student surveys were used to collect the demographic data (race, gender, and perceived status) of each participant. These were collectively merged to answer the research questions.

Research Questions

Two research questions guided this study. The research questions are:

1. How are CERs constructed in small groups in an undergraduate introductory chemistry course? Does gender, race, or perceived status make a difference in the CER formation?

CER Documents

CER Document Analysis-Chemistry Content.

The CER documents of this study were used to analyze the students' understanding of chemistry topics. In this study, the CER activities focused on gas laws, solubility, and buffers. The third CER is the focus of this dissertation, but all the CER data are presented as background pertaining to this study.

The collected CER documents were graded and scored using a rubric (Figure 3, previous chapter) that was based upon the work of Sampson and colleagues (Sampson et al., 2015). The claim, evidence, and reasoning in each CER document were graded to evaluate the individual student and group understanding of the chemistry concepts. The rating scale for the claim, evidence, and reasoning area was one to four.

After each CER paper was scored, the mean claim scores were calculated for all the students. The mean scores of the small group claim scores were calculated the same way. This process was done for the evidence and reasoning component as well.

Mean scores of the small group claim, evidence, and reasoning are described to provide a clearer understanding of the use of the CER documents, which was used to track the change in CERs from individual to the small group. Figure 4 represents the individual and small group mean rubric scores for all CER activities. The vertical axis indicates scores, which ranged from zero to four. The horizontal axis reports the individual and small group CER activity. From Figure 4, it is evident that the CER of the groups improved over time. The evidence revealed as groups worked together, they improved in their ability to construct correct CERs. Among the individual scores, the second CER was challenging for the students. In the other areas, the individual students were consistent (but improved slightly) in their use of evidence. The students, however, struggled in integrating reasoning into their CER. This area had the greatest degree of fluctuation in the student CERs.

In Figure 5, the individual and small group mean scores are reported of the third CER activity. These are total scores, as opposed to being disaggregated as shown in Figure 4. This activity covered the topic of buffers. Across the individual and small groups, the mean rubric scores were higher for the claim than the evidence and reasoning. The mean rubric scores of the reasoning were lower than the claim and evidence scores. The reasoning was the most difficult aspect of the activity as demonstrated by the individual and small group scores.

This dissertation, however, is focused on the CER scores of select groups who completed the third activity. Pseudonyms are used for the students. Table 3 displays the individual and mean scores of the students in the third activity, who comprise this dissertation. It also shares the group scores.

Figure 4

CER Mean Rubric Scores

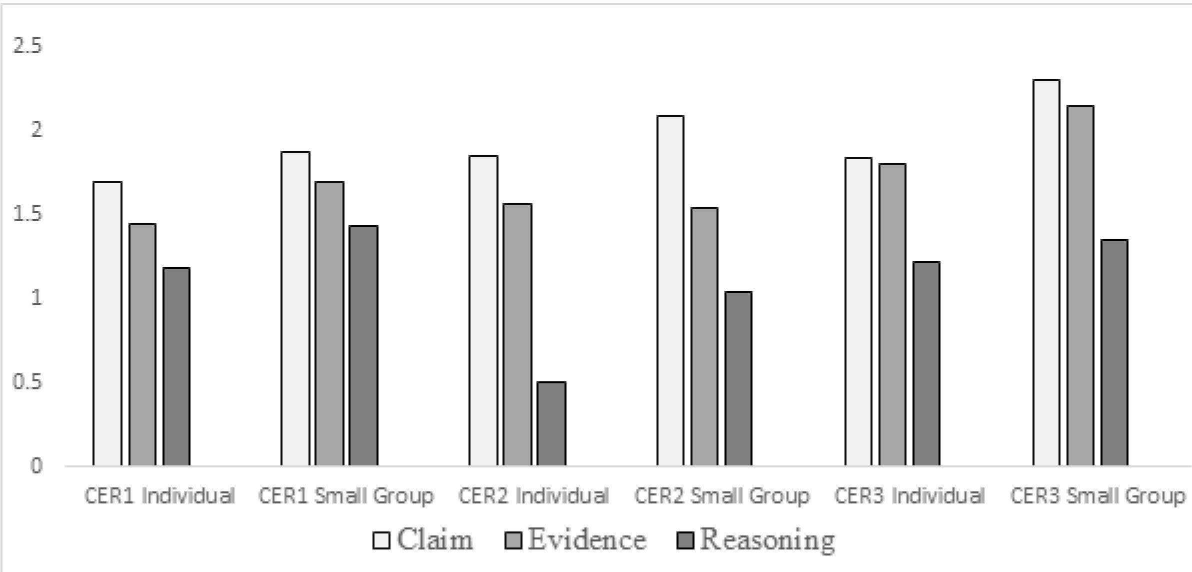


Figure 5

CER 3: Buffers- Mean Rubric Scores

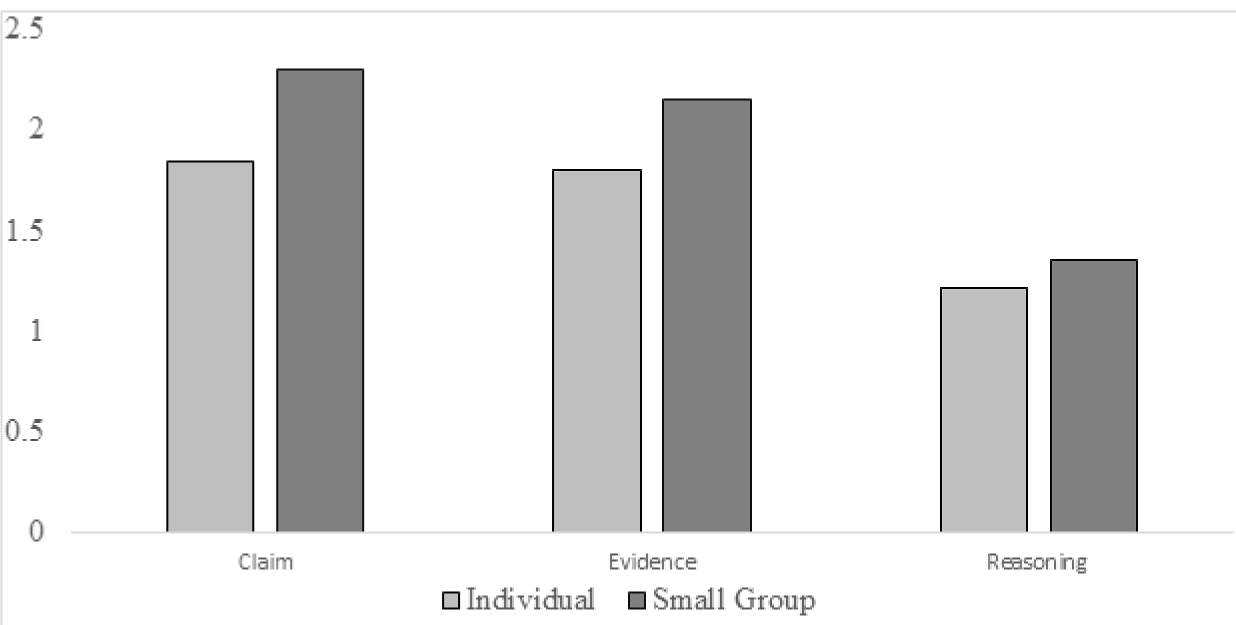


Table 3

Results for CER 3

NAME	Claim	Evidence	Reasoning
Amy	1	1	1
Adrian	1	1	1
Angel	1	1	1
Group 1- Score	1	1	0
Tony	1	2	2
Jake	1	1	1
Group 2 -Score	1	1	2
Todd	2	2	2
Josh	3	2	1
Group 3 - Score	2	1	2
Calvin	3	2	2
Nick	1	2	3
Group 4 - Score	2	2	3
Hailey	4	3	3
Fran	2	2	3
Group 5 -Score	2	2	3

Table 3 (con't)

Results for CER 3

NAME	Claim	Evidence	Reasoning
Beatrice	1	1	1
Riley	1	2	3
Group 6- Score	1	2	1
Individual Mean	1.7	1.7	1.9
Group Mean	1.5	1.5	1.8

CER Document Analysis-Explanation Type/ Explanation Level/Knowledge Transfer. The explanation found in the individual and small group CER documents was examined using the Flow of Discourse Framework (Hart & Hoon, 2007). The Flow of Discourse Framework categorizes discourse (in this case the written CER documents) as description or explanation. Description uses more evidence-based and observational data when writing the CER. However, explanation uses science concepts and theories when writing the CER. These categories (explanation and description) describe the type of explanation that the student/group used to construct their claim, evidence, and reasoning during the third activity.

The designation of explanation or description was determined by the content of the CER document. A CER document was classified as description if it contained 50% or more descriptive ideas. Similarly, a CER document was classified as an explanation if it contained 50% or more explanatory ideas. Fifty percent was selected as the decision point because more than 50% would be a small majority of the text.

The explanation level was also described as Low (Lo), Moderate (Mo), and High (Hi). The category of Low was assigned to a document with 50% of descriptive or explanatory ideas.

The category of Moderate was assigned to a document with 60-75% descriptive or explanatory ideas. The category of High was assigned to a document with 75% or more descriptive or explanatory ideas. By using these parameters, the researchers of this study were able to appropriately describe the CER documents' explanation type and level.

The CER documents were examined for their type of explanation (explanation or description). Explanation (theoretical and conceptual knowledge) and description (observational/evidence-based data) describe the type of data that was used to complete the CER documents. For example, the Group 4 CER document described the claim, evidence, and reasoning as explanation using the following phrases: 1) the acidic precipitation is caused by the atmospheric CO_2 becoming carbonic acid, 2) increases the acidity of water overtime as CO_2 is released into the atmosphere, and 3) if acidity increasing over time, this means the waters ability to maintain a certain pH is decreasing, and 4) the increased concentration of CO_2 is transferred to the ocean through precipitation. The evidence was classified as explanation because it used scientific concepts and theories to make connections between the CO_2, acid rain, pH, and the existence of marine life.

Additionally, the Group 3 CER document was evaluated as description based upon the following phrases in the CER document: 1) top left graph shows that as atmosphere CO_2 level rise ocean CO_2 levels rise, 2) bottom right graph predicts the future given growing rates of CO_2 in the atmosphere, and 3) the ocean will become very acidic. In addition, students from other groups used phrases and terms such as: 1) fish die as the pH increases, 2) becomes more acidic, and 3) ocean pH decreases. This evidence was classified as description because there was no conceptual or theoretical knowledge provided of the data. This data was based on observations or provided to the students as information on graphs and charts.

Among these scores, they were rated as Low, Moderate or High. Low scores are characterized by minimal evidence and no science content. Example statements related to a low descriptive score are carbon dioxide increases, trend of carbon dioxide decreases, buffer can't balance acid; while low explanation score examples are increase carbon dioxide, lower pH range because of precipitation, and buffer cannot balance enough acid. Moderate score statements are characterized by some scientific theories and some evidence. Example moderate descriptive score statements are atmospheric carbon dioxide becomes carbonic acid, lower pH range because of precipitation and pH is decreasing, while a moderate explanation statement would be increase acid. High descriptive score statements are characterized by a prominent scientific theory or concepts, and evidence that is linked to science concepts. High descriptive score statements are carbon dioxide increases, trend of carbon dioxide decreases, buffer can't balance pH as acid concentration increases, and decreasing the concentration carbon dioxide increases pH of water; while a high explanation score statements are seawater becomes acidic the coral reefs begin to dissolve, carbon dioxide forms carbonic acid when placed in water, and as atmospheric carbon dioxide increases ocean pH decreases.

Table 4 shows the combination of the CER document score and the type of idea explanation. In this table, there is a value on explanation over description. Being able to explain one’s idea thoroughly, using theories and connecting ideas, is of value in the learning process.

Table 5 shows the transfer of knowledge from individual to small group across all CERs. This table Again, only the third CER was considered in this study. But this table shows how the students had more explanation oriented CERs over time. That is, more of the groups incorporated more explanations into their CERs. However, descriptive explanations still occurred among individuals and groups. It is also important to point out that groups fluctuated in their CER scores. Likely, as noted before, the CERs were not equivalent in terms of difficulty.

Table 4

CER Document Scoring Scale

Type of Idea Explanation	CER Document Score
LoD	1
MoD	2
HiD	3
LoE	4
MoE	5
HiE	6

Note low description (LoD), moderate description (MoD), high description (HiD), low explanation (LoE), moderate explanation (MoE), and high explanation (HiE),

Among the individual students, there were also fluctuations in the quality of their explanations. Only one student was consistent with their explanation process. This student was consistently high in their explanations. Within the individual explanations, most of the students had low-level explanations during the CER process (11 students). There was an even spread of students with low-level descriptive, medium-level descriptive, and medium-level explanation (6 students). There were few high-level explanations (3 students) or high-level descriptions (5 students) over the three CERs. Understanding how the group dynamics influenced these discussions is the focus of the final analysis.

The second CER is missing in group 6 because the students were absent that day. Table 5 shows the synthesis of the scores, to illustrate the transfer of knowledge from the individual and small group CER documents.

Table 5

Summary of Individual and Small Group Idea Explanation

Group	Individual			Group		
	CER 1	CER 2	CER 3	CER 1	CER 2	CER 3
1	LoD	MoE	LoE	LoD	MoE	LoE
	MoD	MoE	LoE			
	HiD	LoE	MoE			
2	LoD	MoE	MoE	LoD	LoE	MoE
	LoE	HiE	MoE			
3	HiD	LoE	LoE	LoD	LoE	LoE
	MoD	LoE	LoD			
4	HiD	HiD	HiD	LoD	HiD	LoE
	MoD	LoE	LoE			
5	HiE	LoE	HiE	LoD	MoE	MoE
	MoD	LoE	-----			
	LoD	LoD	HiD			
6	MoD	-----	MoD	MoD	-----	MoD
	LoD	-----	MoE			

Note. The level of explanation was categorized as High (Hi), Moderate (Mo), or Low (Lo). The type of explanation was described as Descriptive (D) or Explanatory (E).

Table 6

Summary of CER 3 Individual and Small Group Idea Explanation

Group	Individual CER 3	Small Group CER 3
1	LoE LoE MoE	LoE
2	MoE MoE	MoE
3	LoE LoD	LoE
4	HiD LoE	LoE
5	HiE HiD	MoE
6	MoD MoE	MoD

Note. The level of explanation was categorized as High (Hi), Moderate (Mo), or Low (Lo). The type of explanation was described as Descriptive (D) or Explanatory (E). In group 5, the third group member was missing during this CER.

To check if the scores illustrated the transfer of knowledge, individual and group documents were examined using a comparative analysis (Miles et al., 2014). This analysis allowed the researchers to trace the movement of ideas and words from the individual to the final CER. The ideas were traced by looking to see if similar word phrases, ideas, patterns, and thoughts were present on both individual and CER documents. If the ideas were carried through, the knowledge was transferred.

Table 6 shows the individual and group scores, which show how the explanations changed in this study. In examining how ideas were transferred from individuals to the small groups, it was clear that certain people were influencing the presented ideas. That is, if a LoE description was present in the individual document and the final document, then the person with LoE ideas was clearly influencing the conversation. The second question in this study examines potential areas that may influence this transfer.

CER Analysis Summary

In summary, the analysis of the CER documents described the explanation type and level of each individual and small group CER document. This analysis revealed that most students improved in their ability to write individual CERs over time when comparing CER activity one to CER activity three. However, integrating reasoning into the CERs was the most difficult for the students. This was not unexpected as other authors have noted the difficulty students have in using reasoning in their CERs.

It is also evident that most small group CERs improved from description to explanation level. This may have been a result of the opportunities that students had to practice building their CERs over time. This will be discussed in the last chapter.

Finally, the small group CERs became more blended and explanatory overtime. Again, having an opportunity to practice building CERs may have contributed to these final scores. This will be further discussed in the last chapter.

Audio Recordings

Audio recordings were made during the third and final CER activity. These recordings were taken of selected small groups, which the researchers identified as being important groups to record. The groups were selected based on the research team's observations about each group's interactions, group discussions, and diversity during the first two CER activities. The researchers decided these small groups would yield the most robust data.

The researchers introduced the audio recordings during the second CER activity to get the students used to being audio recorded. The audio recorders were placed at each small group table during CER 2. They were moved around the table at this time to determine which spot provided the best sound. A review of the audio recordings resulted in the identification of spots for the recorder. During CER activity three, the recorders were placed in these spots, and the group was recorded during the entire class period.

The Group Discussion Analytic Framework. The audio recordings were transcribed and analyzed using the Science Classroom Discourse Framework (Mortimer & Scott, 2003). This framework classified science classroom interactions as authoritative or dialogic. Authoritative interactions represent one view or perspective, while dialogic interactions represent the view or perspective of two or more individuals (Aguiar et al., 2010). Dialogic and authoritative characterizations of interactions were the focus of this analysis.

The Analysis of the Group Discussions. The audio recordings of each small group were examined by one researcher to determine how the student discussions took place, and who influenced who. These recordings were reviewed for their authoritative and dialogic nature. The small group discussions were examined for individual contributions to the discussion. The researcher listened to the audio files and reviewed the transcripts to identify the different types of talk. Each sequence of discourse was noted as dialogic, authoritative, or not applicable. Notations were made about these conversations and recorded in a master file. Then the audio data were examined by gender, which was done by noting if the student was male or female.

The audio recordings revealed two major findings of the student interactions that took place during the small group discussions. The first finding showed that male groups engaged in more dialogic discussions while the second finding found that female groups were more authoritative. Table 7 shows the group, gender, type of talk, and time intervals of the audio recordings.

Table 7

Talk use in different groups

Group	Gender	Type of Talk	Time 1	Time 2
1	Female	Authoritative	15:30-21:26	21:27-23:30
2	Male	Dialogic	15:15-20:13	20:16-24:12
3	Male	Dialogic	16:00-24:17	25:56-33:00
4	Male	Dialogic	15:21-16:48	16:50-22:55
5	Female	Authoritative	14:21-22:00	25:00-26:31
6	Female	Authoritative	16:00-18:36	18:45-21:23

The male student interactions were more dialogic. These discussions were characterized by the exchange of ideas and thoughts among group members. For instance, an exchange between two group members leads to the other member giving a complete explanation about buffers and ocean acidity. A small portion of the conversation is below."

An example of the dialogic conversations that took place between male students in Group 2 is shown below:

Student 2: “The ocean will be more acidic as we progress into the future.”

Student 1: “You can see here obviously- like yes - we're gonna be a lot worse in about 100 years. We put a lot of stuff, like toxic waste, in our oceans. Because I mean clearly that has everything to do with …. our emissions.”

Student 2: “Waste, pollution, the composition of the shells, coral and skeletons -- all contributes to the ocean becoming more and more acidic.”

Student 1: “More fish are dying, yeah, like yes.”

Student 2: “Just write that as evidence.”

Student 1: “I mean the ocean has to be surprisingly acidic. I wonder if plastic decomposing in our oceans is causing it to be more acidic. It’s possible in the U.S., right? Like the tons of waste.”

Student 2: “Basically that and like in 100 years she will be more acidic because of the decomposition of shells, corals, and skeletons and the toxic waste and pollution.

During this discussion, each group member contributed equally to the small group discussion; each group member shared their ideas and thoughts.

In contrast, the female interactions were more authoritative. The small group discussions were dominated by the perspective of one individual. The sharing of ideas and thoughts was minimal during the female discussions. An example of an authoritative female group discussion that took place in Group 5, and is shared below:

Student 1: “ My claim is the buffering capacity of ocean water has decreased with time as the CO_2 in the atmosphere has increased.”

Student 2: "And I said, decrease with time because I used evidence. And then what is next"

Student 1: "Okay, so buffering. "Oceans have decreased over time or with time. Decreasing with time so our evidence is a pretty picture too."

Student 2: "Yeah, it's usually from the chart on the left which that some of that comes from the atmosphere can you explain with one of the gases strong increases industry."

Student 1: "Yeah, I can say it is from the picture shown."

Student 2: "Right on the chart at the bottom it shows that the increased density increases the dead fish. CO_2 has increased while the pH has decreased which have caused the acidification."

Student 1: "We talk about increased CO_2 coming from industry. The increased acidity like CO_2 increases acidity. The acidity results from increased CO_2. Okay and then I can say due to this evidence from the whole chart many of the ocean wildlife especially those not used to calcium carbonate will not be able to survive."

Student 2: "Yeah, Is this lowering the pH."

Student 1: "Does it look like it's like 100 gallons of water. A quarter of the atmosphere isn't nothing. "I was just reading that many original species will not be able to survive as $CaCO_3$ becomes bicarbonate becomes HCO_3. I guess that's good and then the justification of the evidence so we can talk about it in class. It was discussed I guess for buffers you have to have a weak acid and its conjugate."

Student 2: "The buffering capacity increases with a weak acid and a strong conjugate. Yeah! So usually it consists of salt. Because the acid becomes the strong buffer. We could talk about the calcium carbonate and something with the bicarbonate and the carbonate. Bicarbonate is carbonate's conjugate base, right? Yeah. Wait, is it? Yeah, yeah. Or is it conjugate? No, it's conjugate base carbonate, or no wait, bicarbonate."

This conversation took place in a two-female group that resulted in a CER document with moderate explanation (MoE).

The major findings suggest that males participate in more dialogic interactions, while females engage in more authoritative interactions. These interactions are important is how the final group CER is developed. More dialogic discussions support the learning of all students, while authoritative discussions support only the learning of a limited number of students.

Student Surveys

Demographic and Perception Analysis (Participants). The student surveys were developed by researchers of this study to collect the appropriate demographic information. The student surveys were given to the students during the third CER activity. The survey asked questions about demographic information (race and gender) and the perception of their group members about their academic status (e.g., who is the A student?). The status question is the perception of their group members as chemistry students. The tables below show the information collected from the surveys.

Table 8 shares the demographic composition of the students who participated in the course. The table gives the race, gender, and total population of the students in the class. In addition, the percentages of race and gender are provided.

Table 8

Class Demographics

Population	49		
Race	36-W (73%)	8-AA (16%)	5-A (11%)
Gender	33-F (67%)	16-M (33%)	

Note. In this table, gender is denoted as Male (M) or Female (F). The race is categorized as African American (AA), White (W), and Asian (A).

Table 9 displays the demographic composition of the participants who make up this study. This includes the small groups and the individuals who make up these groups. Race, gender, and perceived status are displayed. In this table, it is again important to note that all groups are either male or female, with three groups identifying as female and three groups identifying as male. All groups consisted of White and Black students, except for one group that has an Asian male.

In terms of groups, Table 9 shows that all White males were viewed by their peers as having high perceived status, while all Black females were rated moderate perceived status. No group had a member who was perceived to have low status.

Table 9

CER 3 Demographics of the Individuals and Small Group Members

Group	Race	Gender	Perceived Status
1	1-W 2-B	3-F	1-Hi 2-Mo
2	1-W 1-A	2-M	2-Hi
3	2-W	2-M	2-Hi
4	2-B	2-M	1-Hi 1-Mo
5	2-W 1-B	3-F	2-Hi 1-Mo
6	2-W	2-F	2-Mo

Note. In this table, gender is denoted as Male (M) or Female (F). The race is categorized as African American (AA), White (W), and Asian (A). Perceived status is described as High (Hi), Moderate (Mo), and Low (Lo).

Graphical Representation of the Analysis

The graphical representations of the analysis represent an overall summary of the findings of this study. The graphical representations depict the findings from the CER documents, audio recordings, and student surveys. The information included in the perceived status, explanation type, and explanation level of both the individual and small group. Table 10 summarizes the data that is presented in the graphical representation of the analysis.

Table 10

CER 3 Individual/Small Group Explanation and Status Results

Group	Description
1	Adrian is a high-status White female with low explanatory ideas. Amy is a moderate-status Black female with low explanatory ideas. Angel is moderate status Black female with moderate explanatory ideas. Group 1 possesses low explanatory ideas.
2	Jake is a high-status White male with moderate explanatory ideas. Tony is a high-status Asian male with moderate explanatory ideas. Group 2 possesses moderate explanatory ideas.
3	Josh is a high-status White male with low explanatory ideas. Todd is a high-status White male with low descriptive ideas. Group 3 possesses low explanatory ideas.
4	Calvin is a high-status Black male with high descriptive ideas. Nick is a moderate status Black male with low explanatory ideas. Group 4 possesses low explanatory ideas.
5	Hailey is a high-status White female with high explanatory ideas. Fran is a high-status White female with high descriptive ideas. Dalila is a moderate status Black female with low descriptive ideas. Group 5 possesses moderate explanatory ideas.
6	Beatrice is moderate status White female with moderate explanatory ideas. Rose is a moderate status White female with moderate descriptive ideas. Group 6 possesses moderate descriptive ideas.

The first discussion will be of the individual groups. As a reminder, all the groups worked together with the same group members all semester. In Group 1 (Figure 6), there were three females. Adrian is a White female who is a high-status student by her peers. Her CER document possessed low explanation. This was evident in the low use of conceptual and theoretical information she used while constructing her CER. Amy and Angel are two Black females of moderate status according to their peers, and they have a CER score indicating moderate explanations based on their use of concepts and theories.

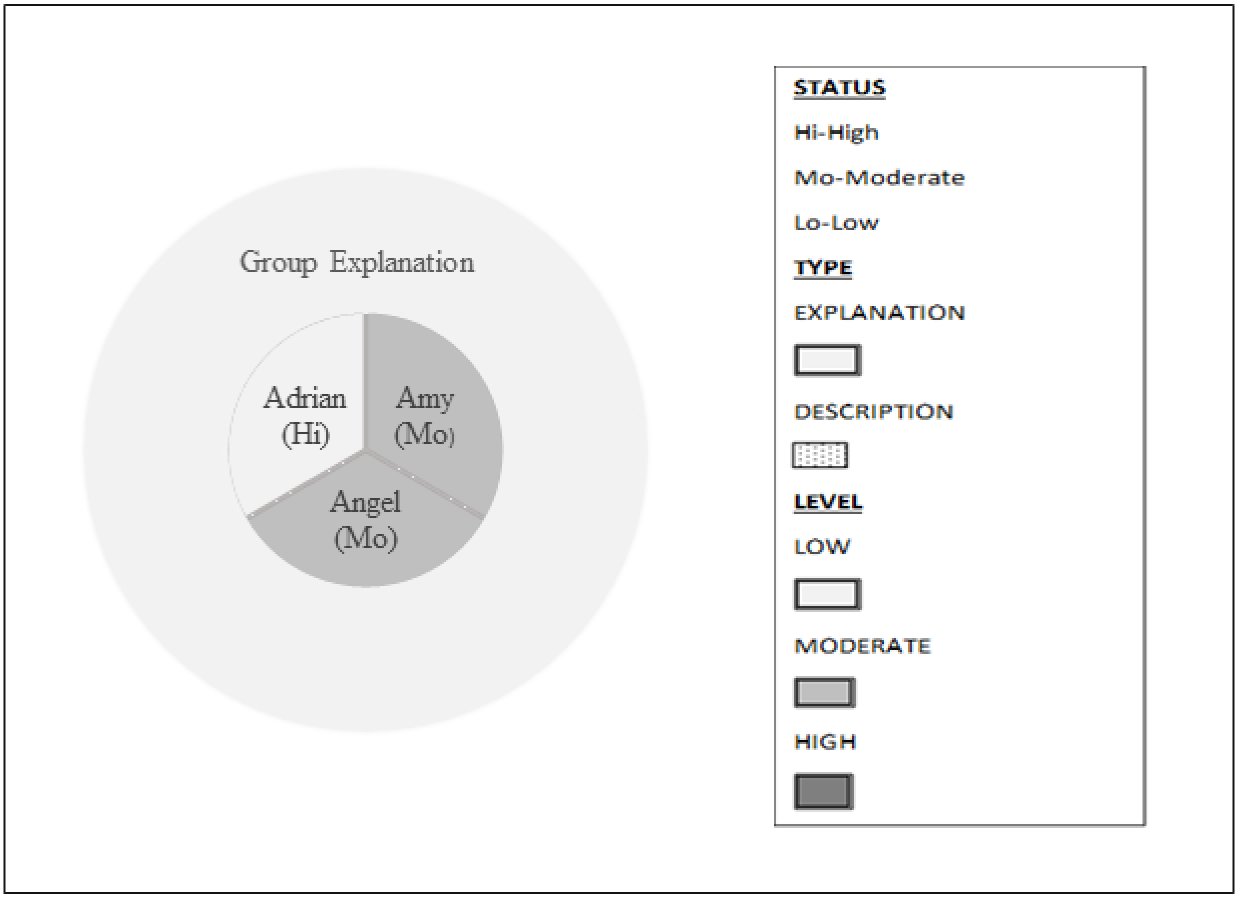
Their original individual CERs changed to a three-member small group CER document that had a low-level explanation. The small group CER document reveals that Adrian’s perceived status as a chemistry student was the most influential factor in the construction of the group CER. This is evident when Adrian says “I don’t know! What did you put?” Amy and Angel’s perception of Adrian’s ability resulted in the construction of a low-level CER. The two defer to Adrian based on their perception of Adrian as a student. This was apparent in the following discussion:

> Amy: “Make a claim and support the claim with evidence from the data
>
> Adrian: “More acidic the ocean. I don’t know is that what you put”
>
> Angel: “the sky is blue I love chemistry too. You are right.

This discussion reveals Adrian's perceived status by the group makes Angel and Amy defer to her even though their CERs contained a higher rating of moderate explanation.

Figure 6

Group 1: CER 3 Idea Explanation and Status



Note. The diagram represents the change in score among the group members. The legend indicates how the other students viewed the group members. Type is the type of explanation, while level indicates the level of the explanation.

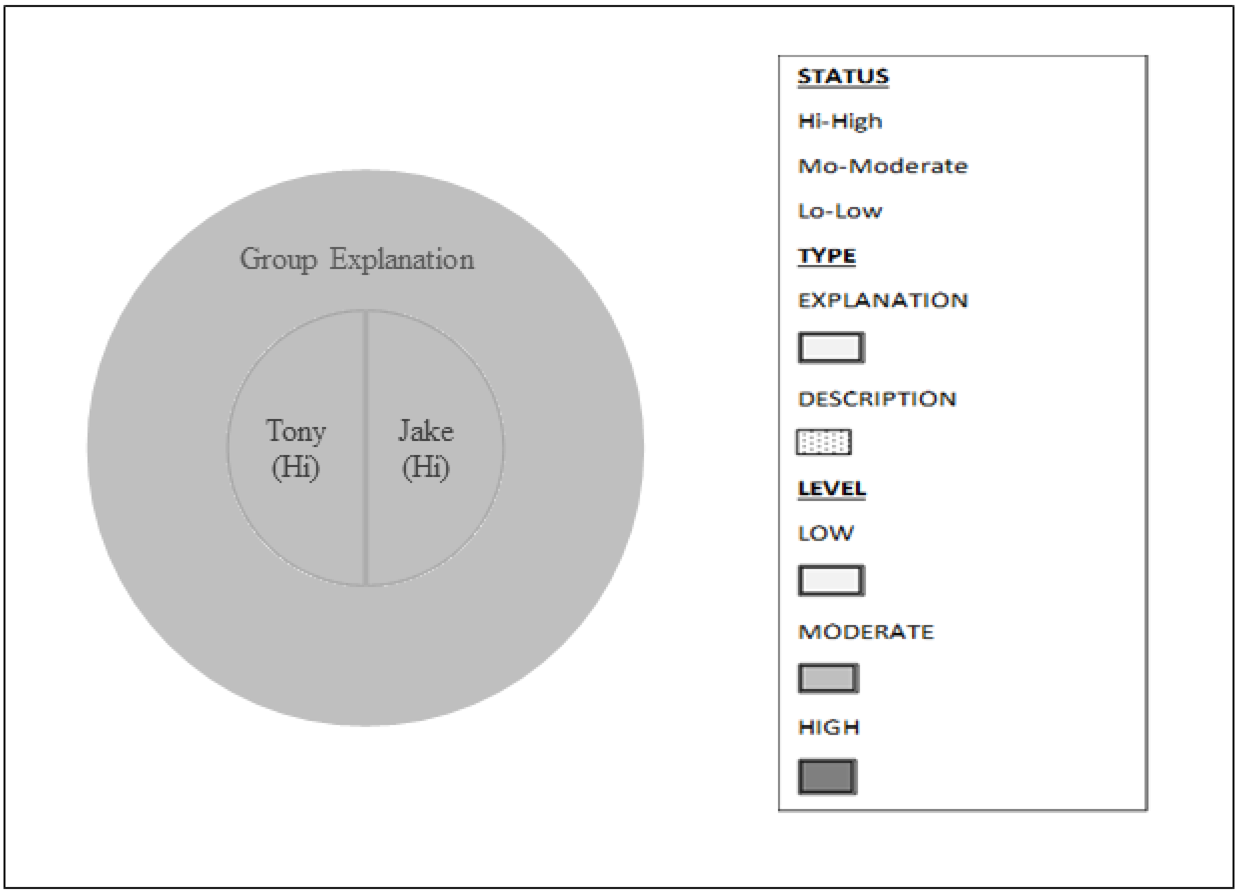
The next group is that will be discussed in Group 2 (Figure 7). Group 2 is a the two-member group comprised of two males, Jake, and Tony. Jake is a high status, White male having a CER with moderate explanation. Tony is a high status, Asian male with a CER of moderate explanation. The two-member group possessed a CER of moderate explanation.

Individually, Jake and Tony possessed the same status (high), gender (male), CER type (explanation) and CER level (high).

The Group 2 CER document (high explanation) revealed no change in CER scores as ideas transferred from individual group members to the two-member group. The CER documents of Tony and Jake revealed that their high status as chemistry students influenced the development of their group CER of high explanation. The group CER of Tony and Jake shows that their perception of each other as they refer to each other while creating the group CER.

Figure 7

Group 2: CER 3 Idea Explanation and Status



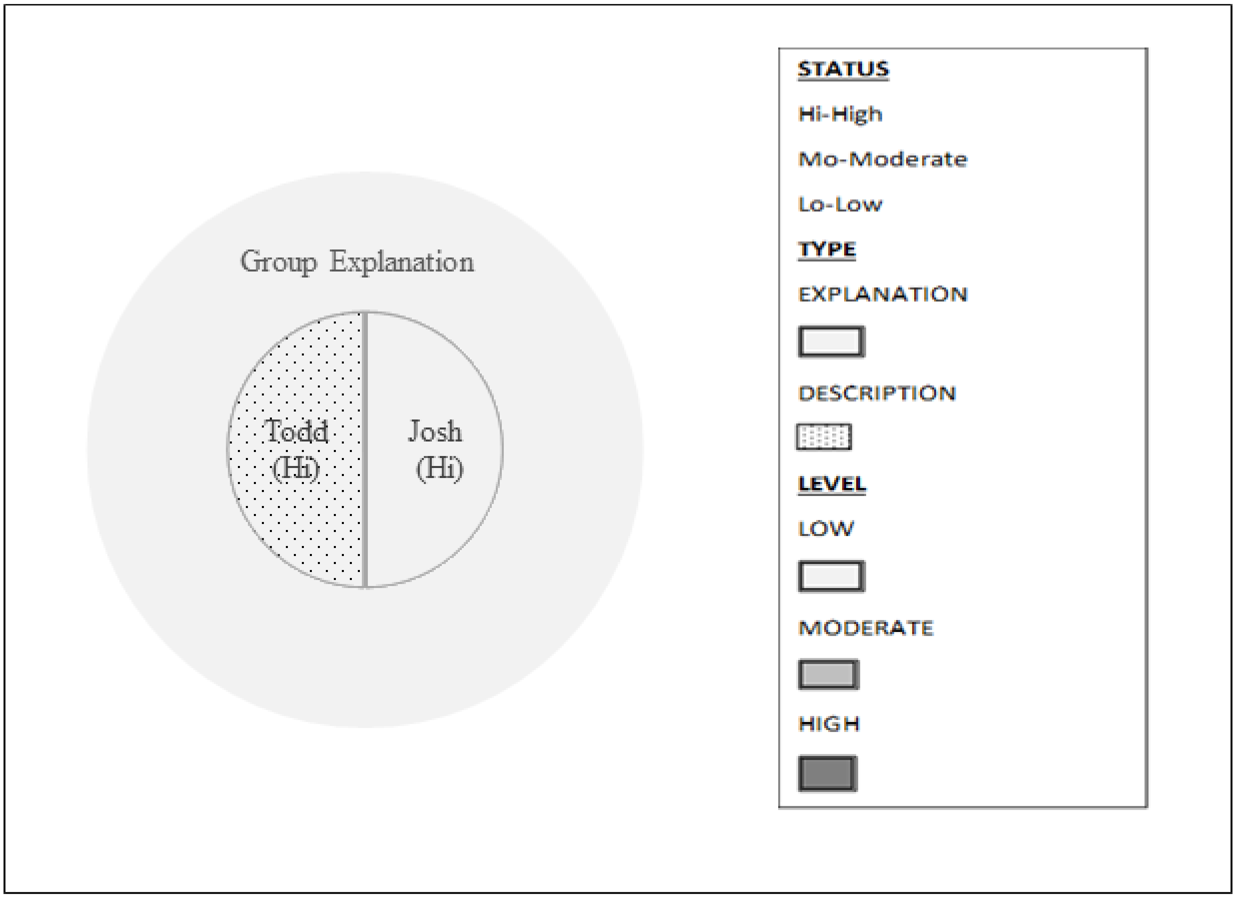
Note. The diagram represents the change in score among the group members. The legend indicates how the other students viewed the group members. Type is the type of explanation, while level indicates the level of the explanation.

Group 3 (Figure 8) is a two-member group consisting of Josh and Todd. Josh is a high, status White male with a CER of low-level description. Todd is a high-status, White male with a

CER of low explanation. Josh and Todd viewed each other as high-status students which resulted in a group CER of low explanation. Josh and Todd are both high-status, White males who possess contrasting levels and types of CER.

Figure 8

Group 3: CER 3 Idea Explanation and Status

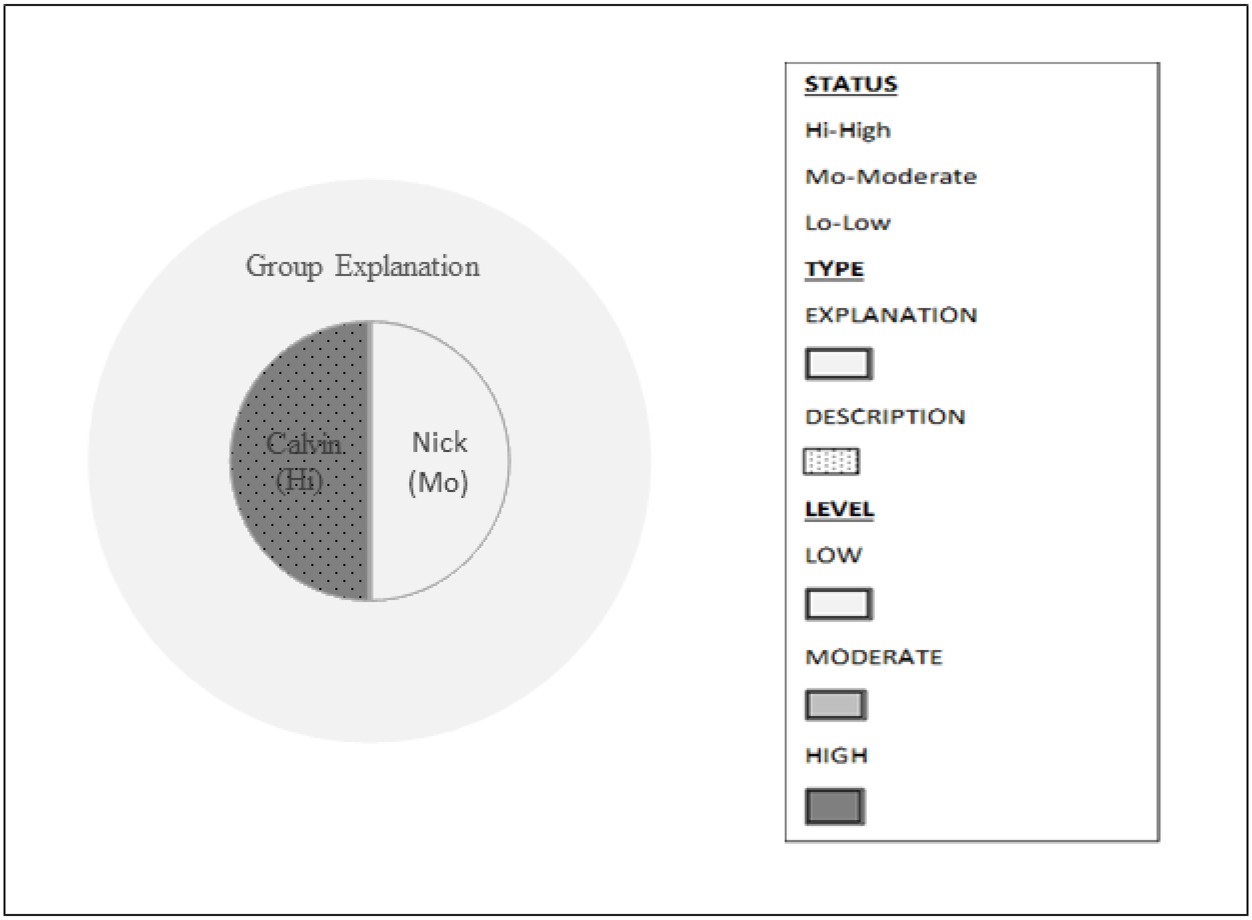


Note. The diagram represents the change in score among the group members. The legend indicates how the other students viewed the group members. Type is the type of explanation, while level indicates the level of the explanation.

The exchange of ideas in Group 3 resulted in a group CER of low explanation. Although both group members were high-status, the individual CER documents of Josh and Todd resulted in a group CER of low explanation. The Group 3 CER document reveals that Josh and Todd possess contrasting levels and types of CER resulting in an overall change in group CER construction from description to explanation.

Figure 9

Group 4: CER 3 Idea Explanation and Status



Note. The diagram represents the change in score among the group members. The legend indicates how the other students viewed the group members. Type is the type of explanation, while level indicates the level of the explanation.

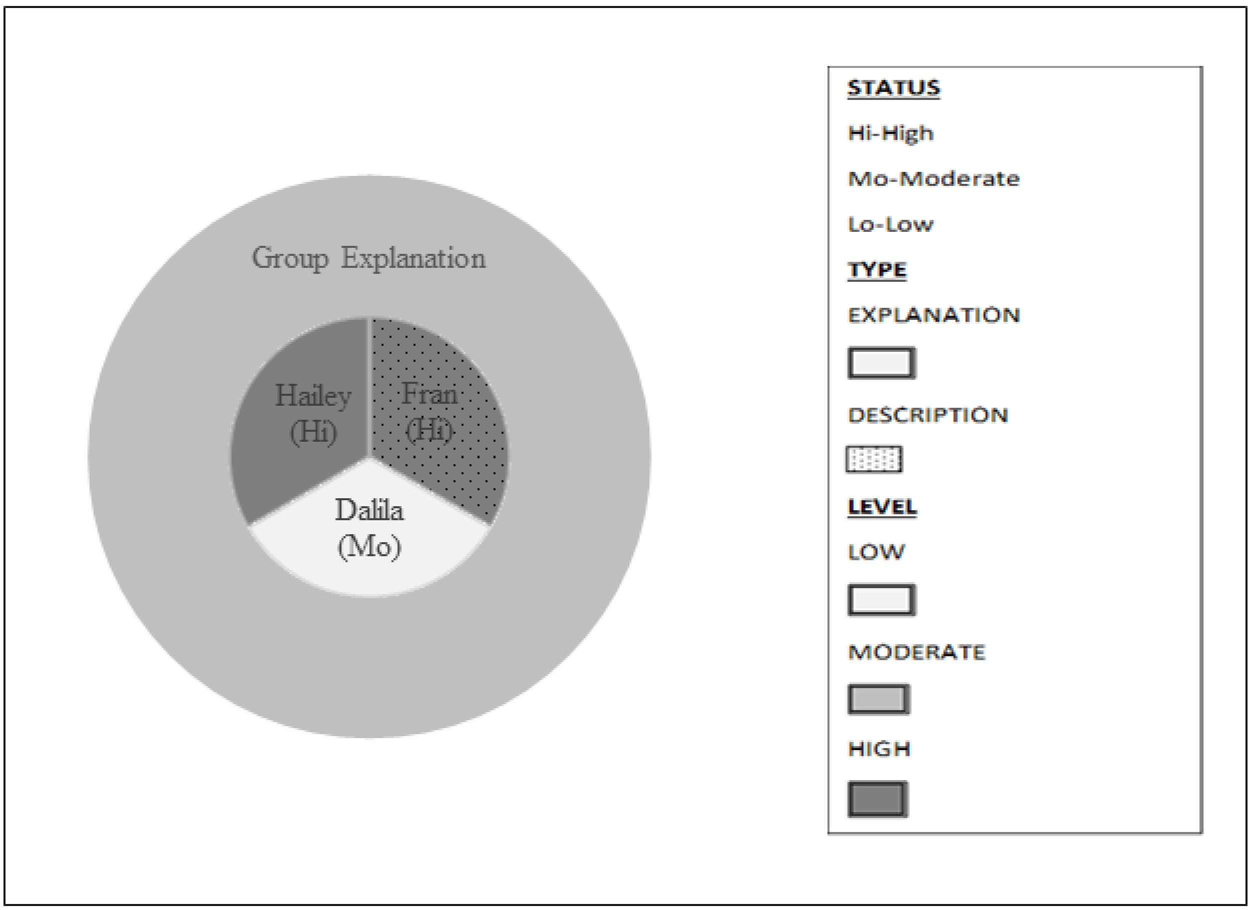
Group 4 (Figure 9) is a two-member group consisting of two Black males, Calvin and Nick. Calvin is a high-status, Black male with a CER of high description. Nick is a Black male with moderate status and a CER with moderate explanation. Calvin and Nick possessed contrasting CER types and levels which resulted in a group CER of low explanation. The Group

4 CER document possessed a low-level explanation. The CER documents revealed that despite the status of Nick, Calvin and Nick exchanged ideas and constructed a CER of low explanation.

Group 5 (Figure 10) is a three-member group consisting of two White females and one Black female. Dalila is a Black female with moderate status and a CER of low description. Hailey and Fran are high-status White females with CERs of high explanation and high description, respectively. The group CER was rated as moderate explanation.

Figure 10

Group 5: CER 3 Idea Explanation and Status



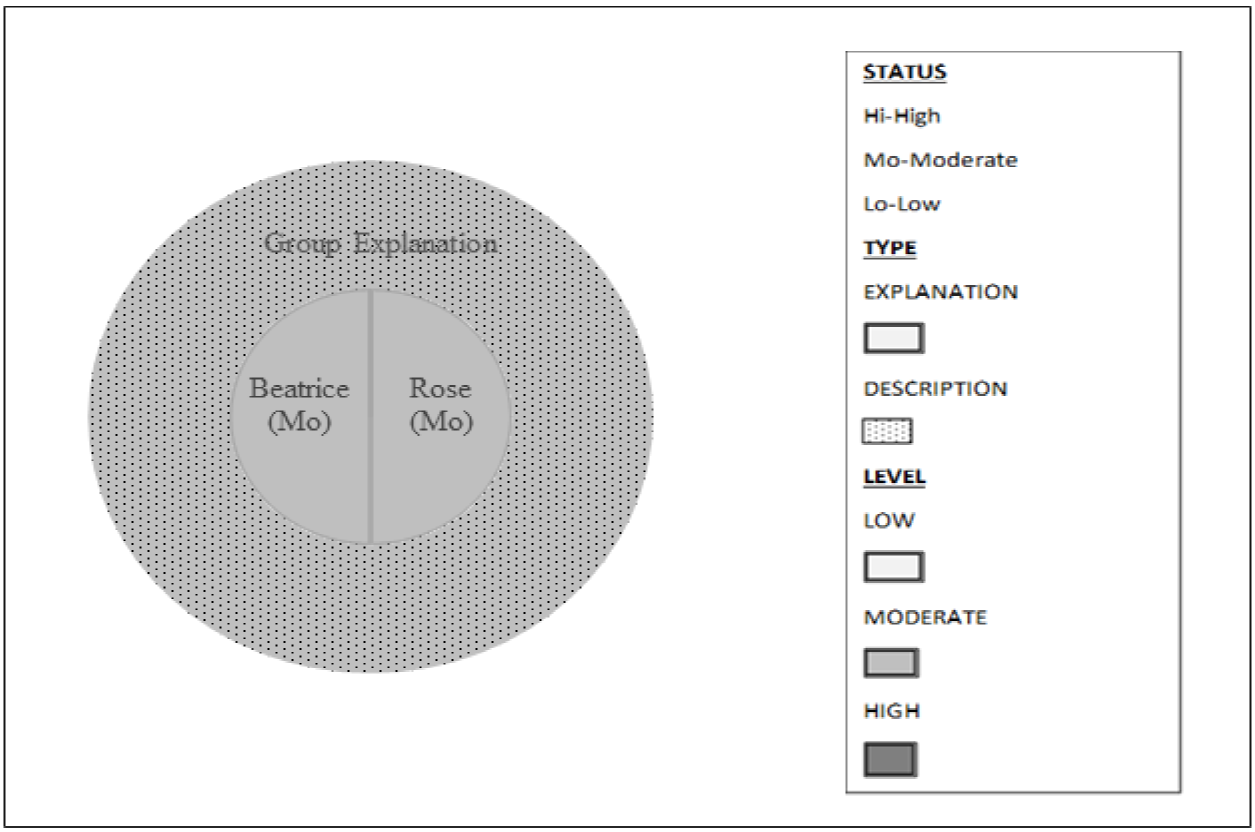
Note. The diagram represents the change in score among the group members. The legend indicates how the other students viewed the group members. Type is the type of explanation, while level indicates the level of the explanation.

The Group 5 CER document revealed that the three female groups consisted of group members with varied status, explanation level, and type. The group CER document revealed that the high-status group members deferred to each other during CER construction yielding a moderate-level group CER document.

Group 6 (Figure 11) is a two-member group consisting of two White females, Beatrice and Rose. Beatrice is a White female with moderate status and a CER with moderate explanation. Rose is a White female with moderate status and a CER possessing moderate description. The group CER of moderate description is indicated in CER construction.

Figure 11

Group 6: CER 3 Idea Explanation and Status



Note. The diagram represents the change in score among the group members. The legend indicates how the other students viewed the group members. Type is the type of explanation, while level indicates the level of the explanation.

The CER scores of individual group members reveal that the two group members possessed levels of CER abilities. The small group CER document showed that Beatrice's ideas did not influence the overall construction of the CER. In addition, data suggest that Beatrice deferred to Rose even though their status was equal, and her understanding of the topic is better.

Summary. In examining the figures above, there were not any specific similarities that existed between all groups. However, five of the six groups had low explanation levels while only one group had descriptive explanation.

CHAPTER 5

CONCLUSION

This chapter summarizes the results and findings of this study by synthesizing the data presented in Chapter 4. The data are also used to draw relevant conclusions about the results and findings of this study. A discussion about the implications and recommendations for future research conclude the chapter.

The lack of interest and participation in STEM fields has been a longstanding problem facing the field of science education. Projections show that the United States will require many to enter the STEM fields in the next 10 years. In meeting these challenges, colleges and universities must examine how science courses are taught as a solution to addressing this shortage of STEM workers in the field.

The purpose of this study was to examine the construction of scientific explanations in small groups, along with considering the influence of race, gender, and status on these explanations. This study assumes that when students have opportunities to engage in aspects of science, they will build their understanding and confidence in doing science and potentially persist in the field. This study is the first step in increasing diversity in the STEM workforce. It looked at how students constructed explanations under the conditions of the study and how groups influenced the construction of the explanations.

This study was guided by the following questions: How are CERs constructed in small groups in an undergraduate introductory chemistry course? Does gender, race, or perceived status make a difference in CER construction? The answers to these questions are discussed in the following paragraphs.

How are CERs constructed in small groups in an undergraduate introductory chemistry course?

In this study, the resulting CERs came from the group process. In general, the students improved their CERs when they worked in groups. Furthermore, there were differences in the contributions of the female and male students. Simply put, the students improved in their constructions, but the students contributed differently to this process. The following paragraphs will discuss this assertion in more detail.

In this study, the small groups were a key factor in the creation of CERs. This result is not surprising given the evidence surrounding the importance of active learning (Freeman et al. 2014) and small group discussion (Xiaoshan et al., 2020). In this study the individual CER scores were lower than the group CER scores. This difference occurred over time and in the third CER. However, the CER score within a group typically improved gradually over time. The following paragraphs will discuss why these differences may have occurred.

To begin, interactions between students are essential in the advancement of their knowledge. The interactions of students dictate the discussions and type of conversations that occur within the group. These discussions and conversations are essential in building linkages between current and future understandings. This advancement of knowledge can be understood through generative learning theory (Osbourne & Wittrock, 1983; Wittrock, 1992). This learning theory stresses the importance of strengthening the linkage between current concepts or understandings in students' minds. In this theory, as students engage in an activity, linkages are strengthened between ideas and concepts. In the case of CERs, students built their understandings by repeatedly contemplating claims, evidence, and reasoning. As they had more experience with these areas, students fortified their understanding of the content and the process of CER. As a result, their use of the CERs improved (slightly) as they had more experience.

The theory of generative learning reinforces the importance of active learning settings (Bonwell & Eison, 1991). The new knowledge is introduced during small group discussions and while creating small group CERs. Students, in active learning settings have a knowledge exchange as they use the CER framework. Students discuss CERs while also building relationships between the concepts. In this study, these active learning environments resulted in improved individual and small group CERs. Generative learning theory, along with active learning were conducive to improved CERs. Ultimately, learning requires students to be active learners during the process of knowledge construction.

Along with the process of generative learning, the quality of the conversation associated with the building of a CER needs to be considered. In this study, the quality of the talk was noted as either dialogic or authoritative (Hart & Hoon, 2007). Dialogic discussion involved all students talking to one another and taking into account the presented ideas. Authoritative discussion involved one person guiding or driving the discussion. These different types of discussion resulted in the improvement of CERs, but not for the reason hoped.

Among the dialogic group, the outcome appears to have resulted in real learning. Students improved their knowledge as they collaborated. This transfer of knowledge throughout the group allowed students to connect prior experiences, which resulted in meaningful learning. Among the authoritative group, the learning may not have benefitted everyone. One person guided the discussion. Thus, everyone had an improved score, but learning was limited within the group. A closer look at this data reveals these discussions differed by gender.

The other way in which the CERs were evaluated pertained to the type of explanation that was presented on the forms. Analysis found that the CERs were rated as either explanation or description. Explanations discussed the phenomena and represented a higher level of understanding. Students applied the data to a concept. Descriptions provided only an overview of the phenomena with little connection to the topic. In this study, the groups moved from descriptive CERs to explanatory CERs over time. For most of the groups, this transition happened by the second CER. This overall trend was observed among individuals, as well. Most of the students moved from descriptive to explanatory.

This change in description of the phenomena is likely attributable to the small groups. Again, active learning (Prince, 2004) and small group studies (Golub et al., 1988; Laal & Laal, 2012) have reinforced the importance of discussion as a pathway to learning. As the students looked at each other's papers, they began to see how each student constructed the CER. This process of comparing work allowed students to see the limitations of their own work and revise to develop a better explanation. Wright (2021) echoed the value of having students talk to one another to improve their understanding. Only four students continued to present descriptive responses by the third CER.

Xiaoshan et al. (2020) found that when small groups were embedded into active learning, the group members learned together. Cohen (1994) also suggested there was an exchange of knowledge when students in small groups work together. This group learning appears to have happened in the small groups and is evident in the improved descriptions of the CERs. The opportunity of students to work together provided a learning environment, even without instruction on how proceed with the assignment.

One last point can be made about the CERs. The reasoning part of the CER was the most difficult for students, which is not uncommon. Many other researchers have reported on the difficulties that students have in embedding reasoning into their CERs. The complexity of scientific reasoning may contribute to this difficulty. However, with time and practice, students may improve at embedding reasoning into their CERs.

In summary, the CERs improved in different ways over the course of the semester. The final CER demonstrated the learning that had occurred. The CERs were constructed when students engaged in small group discussions and talked with each other by exchanging new ideas and knowledge. These discussions allowed an exchange of ideas and knowledge and an opportunity to examine feedback from their peers and construct explanations based on new understandings. The improvement observed among the students is consistent with studies in the field (e.g., Glassner et al., 2005). However, some variation was found in how discussions occurred during the CERs.

Does race, gender, or status make a difference in CER construction?

In this study, I wanted to know if race, gender, or status influenced the CER construction of the students in their groups. The data revealed that gender made a difference in CER construction, and that race and perceived status did not make a difference in CER construction. In understanding why gender made a difference in CER construction, the authoritative and dialogic group interactions (Scott et al., 2006) that took place within the small groups during CER activities must be examined. In these findings, the male students engaged in more dialogic interactions, while female students engaged in authoritative interactions. These findings are not supported by the literature. For example, Stump et al. (2011) found that female students engaged more in collaborative practices such as group discussions and the exchange of ideas. This finding in this study is opposite of what the literature indicates about the interactions of female and male small group settings.

The data are unclear as to why the females in the groups were more authoritative. One explanation may be that not all of the female students in the group were comfortable with the material (Aguillon et al. 2020) and relied on the student with more confidence (also a female). A longstanding divide in the genders has been documented in terms of science participation, with males advancing in rates not equal to their female counterparts. In this setting, the female students may have not been comfortable with the material and relied on the student who was more confident in her approach (authoritative). The female students were capable of engaging in the material, but they were not confident and relied on the student who seemed most self-assured, resulting in unequal participation in the creation of the CER.

In examining race, Abdel-Monem et al. (2010) reported that participants of color experience improved small group communication and productivity, often more than their white peers. In terms of the communication among the students, some differences were found in this group. The all-Black groups had more dialogic explanations, which could be equated to better communication. However, when it came to productivity, the groups were similar. In all-White and mixed-race female small groups, the CERs improved slightly from individual CER to small group CER. Additionally, the all-White male small group and the all-Black group showed some improvement in CER construction overtime. Among the groups, all performed comparably in terms of the final CER explanation score.

In this setting, while all groups may have developed some friendships among each other that promoted the sharing of information, the Black students may have been better at sharing information. Perhaps they may have been friends previously, which enhanced their discussion.

Or perhaps they felt comfortable with one another and were interested in the material. This phenomenon is worth additional investigation, as research points to gains for all students regardless of race (Abdel-Monem et al., 2010).

When considering perceived status among small groups in this study, significant differences are worth noticing. The turns of talk among individual group members were related to group member status (Bonito & Hollingshead, 1997). The high-status students talked the least and possessed the lowest level of explanation. For example, in an all-female, mixed-race small group, one high-status member did not participate in the small group discussions. The group member who led the discussions and talked the most possessed a lower status. Similarly, an all-male African American group with one high-status and one moderate status student, the group member with the lowest status possessed a higher level of explanation on the individual CER document.

According to Cohen (1994), academic status is the most influential form of status. However, in this study, the quality of talk and talk among students during small group discussions was not determined by the perceived status of the different group members. The data indicate it was determined by another factor: gender. Likely, academic status was not important because students considered other factors. The actual experiment may have been engaging to the students. Looking at data and trying to interpret it was important in breaking down race and status boundaries.

In summary, the examination of this study's data revealed that gender made a difference in CER construction. Perceived status and race did not make a difference in CER construction. Gender made a difference in CER construction based on the type of talk and interactions that took place in small groups. All groups improved over time, however, even though talk was uneven within the groups.

Suggestions for Instructors from This Study

Three recommendations emerge from the data on the use of CERs in classrooms. The first is that instructors should provide students with guidance about how to talk to one another productively. In this study, the students were not provided with instruction about productive talk. Instead, the instructor emphasized having students learn to talk to one another by using the CER framework. More could have been done to help students learn to talk productively with one another.

The second suggestion pertains to the use of CERs. CERS are a good way to help students understand how science proceeds. CERs involve students using real world problems to reason through a phenomenon that is important in science. They are important and have the potential to help more students engage in science topics.

Third, students can use CERs, but they continue to have problems in understanding how to use the reasoning in their explanation, an issue instructors need to consider. More explicit instruction should be provided on how to embed reasoning into the CER.

Contributions of the Study

This study focused on the construction of CER and the composition of these CERs in small groups in an introductory chemistry course at the undergraduate level. The transfer of knowledge among group members plays an important role in understanding science concepts. This study reinforces the importance of small group work in terms of enhancing the knowledge of undergraduate students. The small groups allowed the students to build their understanding of important concepts in science.

Additionally, this study contributes to the literature on undergraduate education by investigating an intervention that can improve undergraduate chemistry instruction. It explored an instructional strategy that may enhance student learning in undergraduate chemistry. By adding to the literature in undergraduate chemistry, this study contributes to the improvement of student learning in chemistry through CERs.

In addition, this study gives science educators a rubric to effectively rate student CERs in the classroom. This rubric may be used as is, or it can be modified for use in the class. The rubric is specific to CERs, which should be used in more undergraduate science classes.

Future Work

At the undergraduate level, learning about science is important. Students come to class with different experiences and backgrounds that influence how they interact with one another and how they make sense of science. This study is the first step in understanding the use of CERs, along with the composition of diverse groups of students that occurs in undergraduate chemistry courses. With colleges and universities serving more diverse populations, instructional practices must be used that promote student learning in science. Therefore, more studies should be conducted that contemplate how to improve undergraduate chemistry and how to involve more students in doing science.

Additionally, more studies should be conducted that examine teacher and student perception about the implementation of active learning and CER strategies in chemistry. This perspective is important. The perspective of teachers and students will allow researchers to understand how to optimize the use and implementation of active learning practices, such as CER. Conducting further research in these areas of science education is very important and can provide important information that enhances science instruction. By addressing these areas of science education, science educators will be better prepared for a diverse student population.

Conducting further research in the areas of teacher and student use of CER in small groups and CER use in race, gender, and status is important. While in this study only gender was found to play an important role, science education researchers must conduct studies that explore the intersection of race, gender, and status in groups. By addressing these areas of science education, science educators will begin to understand how to increase the diversity of STEM fields.

Limitations

The major limitations of this study were the group diversity and the self-selection of small groups by the students. The groups were not as diverse (based on race and gender) as I had hoped at the start of the study. This lack of diversity in the small groups was the result of students self-selecting their group members. The students were allowed to choose their group members during the first week of the semester. The lack of diversity within groups may have influenced the outcomes of the study. It should also be noted as an important decision by the students. Future studies explore why students select their groups, as well as how the composition of groups influences the processes of building their knowledge.

Another limitation was the size of the exceeded study. More student groups should have been included to understand how discussion are cultivated. This study had a preference in understanding specific groups, which were interacting in ways that other groups. More groups would have provided more insights into the nature of the interacts and how they influenced the work of the students.

Despite these conditions, I still have confidence in the conclusions of the study because of the purposeful sampling of the groups, which had some diversity.

Conclusion

This study examined the role of race, gender, and perceived status during knowledge construction in an introductory undergraduate chemistry course. The major finding was that males interacted dialogically, females interact authoritatively, and gender was a more important factor in CER construction than race and status. These findings were revealed through the examination of the CER documents, audio recordings, and student surveys. The results of this study will provide information that guides teachers and science educators about instructional strategies that engage and increase student learning.

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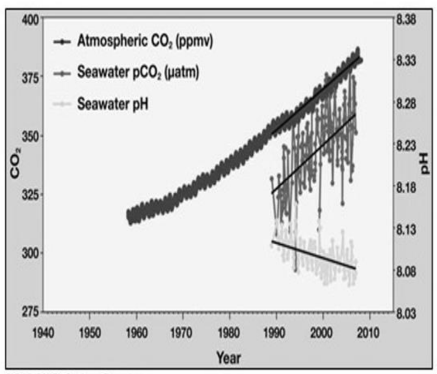
APPENDIX

CER 3 ACTIVITY

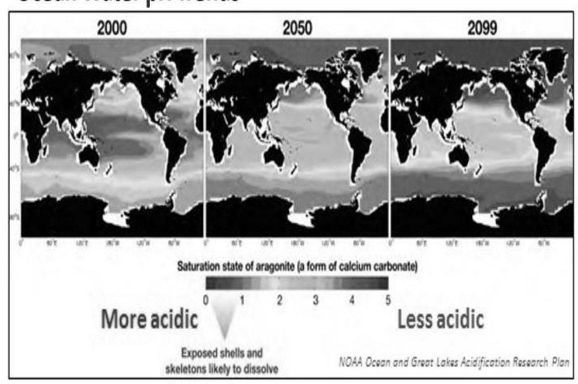
The oceans are habitat to many of the planet's living species. The oceans should have the ability to balance the pH value of seawater. Use the data below and what you know about buffers to explain why scientists have predicted that many marine life will vanish in the future? This means we may not have fresh seafood to eat. Make a claim, support that claim with evidence from the data, and provide your reasoning.

CO_2 Level vs. Seawater pH

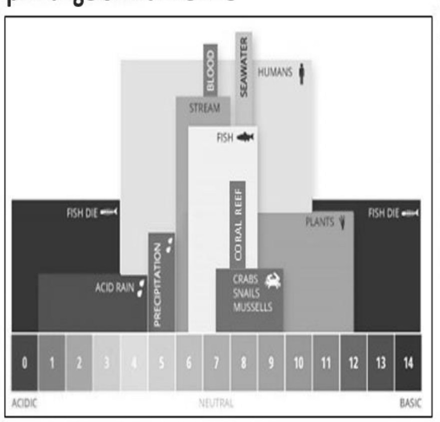


NOAA PMEL Carbon Program

Ocean Water pH Trends



pH Range of Marine Life



CO_2 Reaction in the Ocean