Reaction Rates in Chemistry: A Learning Segment Using the 5E/GRC Instructional Model

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Reaction Rates in Chemistry:
A Learning Segment Using the 5E/GRC Instructional Model

By
Corey James Hollister

A thesis submitted to the Department of Education of The College at Brockport, State University of New York, in partial fulfillment of the requirements for the degree of
Master of Science in Education
December 9th, 2019
Reaction Rates in Chemistry:
A Learning Segment Using the 5E/GRC Instructional Model

By
Corey James Hollister

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Abstract

The following project utilizes the 5E Instructional Sequence and the Gather, Reason, Communicate Instructional Sequence to promote a single-cohesive learning segment. The content covered is that of chemical reactions specifically discussed in the Next Generation Science Standards as HS-PS1-5. Included are a literature review, the learning segment, materials, student prompts, and the rationale behind the various parts of the segment.

*Keywords: 5E model/instructional sequence, gather, reason, and communicate (GRC) instructional sequence, three-dimensional learning, crosscutting concepts, disciplinary core ideas, science and engineering practices*
Chapter 1: Overview

Introduction
The introduction of the Next Generation Science Standards (NGSS) has created a vision that promotes a student appreciation of science (National Research Council, 2012). Coupled with this vision is the notion that science is multifaceted and providing students the opportunity to experience this is imperative for them becoming a scientifically literate member of society. Current science education revolves around a teacher-centered approach that can fail to encapsulate students in the material at hand. With such instruction, educators are unable to instill interest or appreciation for the fields of science and students often opt out of taking it when given the chance. Enabling the vision set forth by the NRC requires modifications or changes to the approaches in which educators teach.

The NGSS implements performance expectations that take a three-dimensional approach to learning through the incorporation of disciplinary core ideas, crosscutting concepts, and science and engineering practices (National Research Council, 2012). Each of the three foundations is unique and provides its own benefits to science curriculum. The idea of crosscutting concepts connects science disciplines and disciplinary core ideas encompass the knowledge that students will obtain. Combining engineering practices with science allows for real-world application and connects modern-day changes to experiences in the classroom. Furthermore, capturing these three dimensions in a science classroom is meant to engross the students in science and make them ready to learn.

Two research-based approaches that have been found to increase student engagement and learning in the science classroom are the 5E Model and the Gather, Reason, Communicate Instructional Sequence (Moulding & Bybee, 2017). Both instructional sequences embody
scientific practices and student-centered learning to maximize the student experience of science. Moulding and Bybee propose using the two instructional sequences in conjunction with each other to further enhance the learning and engagement developed in the classroom. This project aims to construct a unit that embodies the collaboration between the 5E model and Gather, Reason, Communicate Instructional Sequence and is properly aligned with the vision and performance expectations of the NGSS.

The unit itself will follow a 5E Model (Engage, Explore, Explain, Elaborate, Evaluate) lesson sequence with the Gather, Reason, Communicate Instructional Sequence embedded within. Each lesson will be one of the 5E’s and contain components in which students will gather, reason, and/or communicate. The lessons will focus on three-dimensional learning and students will be exposed to exactly which ideas, practices, and concepts they are expected to learn. Constructing the unit will take careful planning and much time to ensure that learning progressions are followed, and students are able to perform to the expectations of the NGSS.

Ultimately, the unit will be utilized in a chemistry classroom to foster student learning in an engaging manner. The goal is then not to only create a learning segment for continued use, but also a template for future instruction. The pieces of the Gather, Reason, Communicate Instructional Sequence and the 5E model will be purposefully placed to ensure coherence of chemistry concepts and relevance to the real-world as well as other science disciplines. Constructing this unit in such a way will allow educators to emulate the unit in other topics and disciplines of their choice.

The role of the review that has been previously developed is to provide evidence-based rationale behind the instructional sequence, selected materials, and driving questions for learning. Much of the research touches on various aspects of the 5E Model and Gather, Reason,
Communicate Instructional Sequence, while the rest of it focuses on three-dimensional learning and teaching strategies for lesson plans. Research-based decisions will be made that capture the essence of learning and focus on the students.

**Project Design**

This project is designed to be a full-length unit sequence that utilizes a Gather, Reason, and Communicate design within a 5E instructional template. The project will consist of lesson plans that use a GRC sequence format to coincide with an overarching 5E model unit plan. The lessons will outline performance expectations using a 3-dimensional (crosscutting concepts, disciplinary core ideas, science and engineering practices) structure, materials, preparatory work, and a sequence of the lesson. Each lesson is comprehensive enough to be followed by a substitute teacher. The sequences of the lessons are outlined in a format similar to the performance expectations. Prompts for students to visualize throughout each lesson will be found at the end of the learning segment. The unit itself will contain the following components:

- Title of the Learning Sequence
- NYS standards/performance expectations that drive the learning
- Overarching disciplinary core ideas, science and engineering practices, and crosscutting concepts
- Each lesson is part of the Engage, Explore, Explain, Elaborate, or Evaluate stage of the 5E and within each lesson students will Gather, Reason, and, if necessary, Communicate (the explore phase will be utilized more than once).
  - Each lesson will contain the following:
    - Lesson performance expectations
    - A list of materials
- Preparatory work instructions
- A phenomenon to be investigated
- Outline student actions in the form of Gather, Reason, and Communicate sections
- Student work to be completed/resources to be used
- Teaching suggestions/instructions during each section
  - Includes driving questions, scaffolding for students, observations/thoughts on improvement
- An overview of how it fits into the 5E model and the rationale behind the structure
  - A rubric for outlining levels of student understanding, which includes:
    - Levels of proficiency for performance expectations and how students meet those levels
    - Recommendations for improvement for students who are not proficient
      - Includes videos, extra work, diagrams, etc.
  - The student action prompts for each lesson plan
    - These are specific actions the students will follow based on what was planned

**Significance of Project**

The implementation of the Next Generation Science Standards will require educators to evaluate their teaching methods and potentially modify them to maximize student-driven learning and engagement. Integration of the 5E Learning Cycle with the Gather, Reason, Communicate Sequence is an opportunity to provide students with engaging learning in an inquiry-driven format. This is not simply the construction of a learning sequence or unit but a collaboration between two research-based approaches to teaching that optimizes three-
dimensional learning. Not only will I have to intertwine the two approaches to make a coherent unit plan, but I will also find and develop materials and driving questions to investigate phenomenon pertaining to chemistry. Included in my unit plan will be the incorporation of my research to provide the rationale behind my decisions. Completion of this process will require much time and careful planning to ensure a fruitful unit that can be utilized in future classes. The completed project will have the potential to serve as a template for different topics in various disciplines of science.
Chapter 2: Literature Review

Contemporary Issues/Trends in Science Education

Technology and Science Education

It could be argued that most individuals who live in developed countries are spending their free time on a handheld device or in front of a screen. This is one piece of evidence for a changing world and as a result, classrooms/teachers have had to adapt in order to maintain the engagement of their students. As of late, many classrooms are going paperless to increase the use of technology and make the material relevant. One study was completed in order to determine the influences of such a classroom in a STEM environment (Chacko, Appelbaum, Kim, Zhao, & Montclare, 2015).

Because technology-based instruction is becoming more popular and hand-written assignments are going out the window, Chacko et al. (2015), set out to determine the benefits of incorporating technology (and no paper assignments) on education and in increasing interest in STEM fields. In order to do this, a study was conducted over the course of two years on a summer science program. This program was catered specifically towards bioengineering at the high school level and utilized technology whenever possible. The courses were comprised of four-week programs that covered topics on diabetes, cancer, HIV/AIDS, and individual research.

The primary methods for learning were discussion, watching videos, completing hands-on laboratory activities, utilizing case studies, topic related games/activities, and lectures (Chacko et al., 2015). By the end of the course, the students were tasked with creating a research presentation using the technological tools they had been exposed to throughout their time. The average number of students was 18 per course and the participation was consistent week to week. The demographics for the students are unknown.
According to Chacko et al. (2015), data was collected using module evaluations that were completed each week. The evaluations specifically addressed whether students felt they understood the topic of study during the week and whether they were interested in pursuing a STEM career after high school.

It was found that in three of the four weeks, 100% of the students felt they understood the material after going through the learning segment (Chacko et al., 2015). In the other week, about 97% of the students felt they understood the topic. As for the interest in STEM, the percentage of students who claimed they would not pursue science decreased from about 13% to 0% after the four weeks. The percentage of students who said they had fun but were unsure about STEM increased after week one and then steadily decreased to about 12%. Lastly, those interested in pursuing a STEM career made up almost 90% of the class by the end.

One weakness with this study is its focus on a bioengineering course taken during the summer. Most students do not take courses during the summertime, so the focus group is not necessarily representative of the general student population. The fact that it is a bioengineering course also changes the student population compared to a general science course taken in high school. An improvement would be to perform a similar study in a typical high school science course with a diverse population.

Chacko et al. (2015) were able to make conclusions based on the usage of a technology-rich classroom. Students were able to demonstrate self-motivation towards learning and build researching skills. The study specifically set out to develop student interest in STEM fields using paperless learning and it was able to do so. This implies that utilizing technology in the classroom would promote student engagement and interest in classroom material. Furthermore, it
can build skills necessary for the 21st Century that may not be built otherwise, such as using the internet as a source of information and filtering out accurate articles and sources.

While not every student will be willing to pursue a job in a STEM field after taking a high school science course, adding technology into the classroom and going virtually paperless will help to maintain student enjoyment. Traditional lecture classrooms with notes tend to turn students away from STEM and technology has proven that it can be useful for learning while also being effective. Not only does it increase the ability for students to communicate with each other and their teachers, but it also provides variation in the classroom that paper assignments may not.

The 21st Century is said to be a digital age and because of this, many classrooms now have one-to-one devices, such as Chromebooks or tablets. Furthermore, interest can be lacking in a classroom that fails to use technology as students become obsessed with being in front of screens. It has been concluded that utilizing technology in the classroom can help students to be more conducive to learning because it improves their attitudes, thus allowing educators to teach more effectively (Gryczka, Klementowicz, Sharrock, & Montclare, 2016).

The implementation of technology helps students to become more engaged with schoolwork and it benefits teachers in the sense of keeping current with research and new teaching methods (Gryczka et al., 2016). Coupled with this, is the idea that some individuals, specifically girls, may leave STEM fields because of their lack of interest. One study was conducted to implement a technology module in a physics classroom in order to garner interest of girls in high school physics.
Gryczka et al. (2016) partnered with a high school in Brooklyn, New York to conduct the study in which a technology-based physics lesson was utilized. Three fellows set out to develop the lesson which was taught to 17 students in a high school physics class. The 17 students were split into two groups, one a control (8 students) and the other an experimental group (9 students). Each student was female and was of varying race.

The lesson involved the use of an online application called Every Circuit, which allows students to build circuits with varying components (Gryczka et al., 2016). Furthermore, the students were able to explore how current flows through a circuit. The activity was completed using packets that contained questions and for the experimental group, step-by-step instructions on how to develop a parallel circuit using Every Circuit. The control group was provided the same packets only with pictures of circuits instead of instructions. They were then expected to use these to create circuits using pieces of paper.

For data collection, a pre-quiz and a post-quiz were provided on series circuits, parallel circuits, and Ohm’s Law (Gryczka et al., 2016). Another tool used was a survey that asked students to rate their experience using Every Circuit. Through analysis of the quizzes, it was found that the online system did help the experimental group students with drawing and understanding circuits. That said, students in the control group were also found to have developed a better understanding of circuits. Based on the surveys, students claimed that they were engaged throughout the online activity and found it useful for learning the material. A teacher given survey indicated that the students who used the online module were more engaged than the students who did not.

One limitation of this study is the fact that the surveys are opinionated and can have variation depending the person completing the survey. One teacher may have felt that students
were engaged while another may have felt they were not; a definition of student engagement may have proved useful. As for the student surveys, a couple students had left questions unanswered. This begs the question of whether some students truthfully completed the survey or whether they filled in random responses. Also, the control group students were not asked about their opinions of the activity. While the focus was based on technology integration, the students who completed a hands-on activity using paper may have thought the activity was just as useful.

Another limitation in using this for a general reference is that the focus group was only comprised of girls. For the study, it makes sense because Gryczka et al. (2016) were specifically studying female interest. However, in terms of making a generalization, more research would need to be conducted for students of all genders.

While the focus was specifically on females, the study does provide evidence of increased student engagement with the use of technology. This is something that can be expanded on in any science classroom. The trick would lie in finding proper modules/websites to utilize depending on the material being covered.

Gryczka et al. (2016) also mention the presence of a learning curve with the technology as students have not previously used or seen Every Circuit. As with all new things, this makes sense and is worth taking into consideration when utilizing different technology for students. While it may be occasionally useful to allow pure student exploration, time constraints may require tutorials by the teacher.

The last implication worth noting is that technology allows the opportunity for one-on-one instruction. Tutorials/instructions may be necessary upon initial exposure to the technology/modules; however, students will eventually become more self-sufficient when using
specific technology. As this happens, they may be able to solve their own problems and work primarily on their own. This allows the teacher time to address individual questions and expand on specific ideas brought up by students.

Claims have been made that hands-on laboratory investigations play a significant role in the science classroom. Without such investigations, many of the concepts being taught are based on memorization and students are unable to see how they apply to any physical reality. A key to successful investigations is through adequate instruction and the occasional demonstration to ensure students understand what they are required to do.

One way in which students can be introduced to a laboratory activity is with technology. Specifically, students could use online modules that introduce a topic and provide visuals of what is expected to help them better understand what is going on at a microscopic level (if needed). A study was conducted to analyze the effectiveness of blended learning using one such type of module known as LabLessons (Jihad, Klementowicz, Gryczka, Sharrock, Maxfield, Lee, & Montclare, 2018).

Blended learning is said to address most, if not all, types of learning styles, which is difficult to do with traditional teaching methods (Jihad et al., 2018). It involves the use of traditional methods, while also incorporating technology and online learning. Blended learning is seen as a bridge between traditional teaching and online learning and has been shown to be effective in the classroom. Jihad et al. were specifically looking into the perceptions of students and teachers on blended learning.

Freshman students in a high school chemistry (of varying demographics) course were tasked with completing online modules through LabLessons as pre-lab assignments to two
different labs (Jihad et al., 2018). The modules took the students through an introduction, put them through a couple simulations, and then asked them a few questions. Responses were deemed as correct or incorrect and students had the ability to go back and change their answers. This is useful information for the teacher to have as it can be utilized by the teacher to alter instruction once students come into class to physically perform the labs.

In order to complete the study, students and the teachers of the classes were asked to complete a survey after the completion of each module. The survey for the teacher asked questions about student enjoyment, ease of grading, improvements, and technological difficulties. The students, on the other hand, were asked questions about their enjoyment, learning, and whether they would recommend the simulations.

Jihad et al. (2018) found that most students enjoyed the pre-lab modules in both cases. They also had the effect of improving student understanding on the topics at hand. Students claimed that they would recommend the pre-lab simulations to other individuals. Teachers also provided positive feedback for the modules. They felt that the students enjoyed the simulations and found that they were easy to use. Specific praise for the modules mentioned the use of visuals and the influence they had on student understanding.

A limitation of this study is its focus in the chemistry classroom. While this is useful knowledge that can applied into other areas of science, the results may not necessarily be generalized for other classes. This is especially the case because modules were only used on two different topics: titration and formation of hydrogen (Jihad et al., 2018). More variation in the modules used could be analyzed in future studies.
Since student understanding increased and both the teachers and students praised the modules, Jihad et al. (2018) were able to conclude that blended learning is an effective tool. Not only does it spark interest in the students using simulations and visuals, but it also helps them to understand their mistakes. Should a student get a question wrong during the pre-lab quiz, LabLessons provides the students with hints on how to get the question correct. This also helps to develop metacognition skills and requires that the students think through the questions with care.

Metacognition is a skill that cannot be taught through paper quizzes alone. It is a skill built by properly prepared teachers and motivated students. The ability of an online learning module to do this is significant because it shows the benefit of blended classrooms and online learning.

Online modules can also help to decrease the time needed to be dedicated to labs as students can be walked through simulations. This provides them with virtual experience in performing a lab so that they understand how to do it when it comes to the actual laboratory investigation.

**Problem Based Learning**

It could be argued that a shift towards increasing student interest in the fields of science, technology, engineering, and math has occurred over recent years. This shift from merely providing students with knowledge in these STEM fields is meant to increase the number of individuals pursuing such careers. With such a change in focus, pedagogy methods must also be altered in order to keep students motivated in challenging fields.

A method that has been minimally researched and said to have positive effects on the performance and motivation of students is problem-based learning (PBL). PBL involves solving
a problem or question through inquiry (Hall & Miro, 2016). Oftentimes, it requires collaboration between students, use of technology, and teachers acting more as coaches. Because of the limited number of studies on PBL, Hall and Miro performed a study on problem-based learning to investigate how it has been implemented across STEM and its impact on student learning.

STEM education is approached in multiple ways and as such, Hall and Miro (2016) aimed to study PBL in four different settings: STEM Traditional Courses (STC, typical high school), Engineering Optional Program (EOP, pre-engineering specific coursework in a specific location), STEM Platform School (SPS, advanced STEM coursework in a typical high school), and Virtual STEM Academy (VSA, hybrid/online STEM courses). Qualitative research has been recently shown to provide a deeper understanding of topics being studied, so classroom observations were utilized for data collection. Over the course of observations, at least three different high schools were observed, and classes were selected at random in various fields of study, such as Honors Physics and Honors Pre-Calculus, except in the case of the EOP and the VSA. All classes in the EOP were observed and only laboratory classes were observed for the VSA.

In order to collect empirical data, Hall and Miro (2016) used the school observation measure (SOM) and the rubric for student-centered activities (RSCA) as the conducted their observations. The SOM assesses instructional practices across various domains, such as instructional strategies and technology use. The RSCA, on the other hand, measures student engagement across various domains, such as cooperative learning and higher-level questioning. After completion of an observation, the observer then created a summary sheet based on a Likert scale for the extent to which a behavior was observed. Furthermore, a reliability analysis was also conducted.
The data was used to determine the different instructional strategies across STEM education settings and the influence of various strategies on student learning (Hall & Miro, 2016). It was determined that EOP and VSA implemented PBL more often than SPS and STC. Students were also found to be more engaged with PBL in an EOP setting. EOP was also found to utilize a teacher as a coach, collaborative learning, and hands-on learning, each of which was coupled with higher student engagement. No statistical differences were found between the educational settings in the case of student discussion, student self-assessment, use of higher-level questioning strategies, and higher-level feedback.

A limitation of the study is its lack of variation in sample populations. The high schools studied were in urban locations in the Southeastern United States. The fact that there were only a few studied brings forth another limitation. While the results are informative and generalizations can be theorized, they do not provide information for rural or suburban schools nor for schools across the United States.

Hall and Miro (2016) concluded that while EOP and VSA approaches to STEM education utilized PBL more often than a traditional classroom, this was consistent with the expectations of the programs. Furthermore, inconsistency in PBL usage in SPS or STC may be due to lack of teacher support. PBL was shown to improve student learning through increased student engagement and interest in STEM. Traditional STEM education was shown to lack in higher-order feedback and use of higher-order questioning strategies, both of which are typically seen in problem-based learning (Hall & Miro, 2016). This indicates potential areas of improvement for STEM classrooms.

Based on the data, it can be concluded that problem-based learning is multifaceted and requires much planning. In traditional classrooms and without proper knowledge, this may be
difficult for some teachers to implement. Increasing the difficulty is the lack of support that some teachers may face in certain schools. Further studies could investigate the support needed to implement PBL and the influence that not having said support has on instruction.

The digital age is said to have many benefits, one of which is ease of access to information. While this information covers a vast expanse of topics, one of interest is the field of science. Technology has increased the capabilities of individuals in developed countries to understand and study science like never before. Teachers can utilize this in the classroom to increase inquiry and scientific literacy through problem-based learning.

Research indicates that using inquiry-based activities, such as posing questions and developing arguments, led to increased science learning in the case of classrooms that are provided supports from those conducting the research. That said, minimal research has investigated the same phenomenon in traditional classroom settings where extra support is not provided. Kang, DeChenne, and Smith (2012) sought to do just this as they investigated the effects of a problem-based curriculum on scientific literacy and inquiry outcomes. The focus of the study was on questioning abilities and inquiry to students’ own questions.

In order to conduct the study Kang et al. (2012) collected data from a suburban high school in the Pacific Northwest United States. The school itself had a student enrollment of approximately 2,400 of which 33% were considered a minority, while the total number of students studied was 175. The class being studied specifically was a ninth grade “Science Inquiry” class that was state mandated. Data was collected over the course of two years from classes taught by two different teachers.
The “Science Inquiry” class was taught using two different curriculums (Kang et al., 2012). The focus curriculum was a problem-based inquiry environmental health science curriculum that engaged students in a field study where they collected and analyzed data from naturally occurring events. As a comparison, 46 students were taught using an alternative inquiry-based curriculum.

Data collection utilized written responses to environmental problems from the students before and after the curriculum implementation (Kang et al., 2012). The pretest outlined a water supply contamination in video format, while the posttest reported contaminated chicken feed causing the deaths of chickens and mutations in offspring in newspaper format. Both tests asked the same questions and required students to respond using Microsoft Word.

Kang et al. (2012) first analyzed data between groups taught by the two different teachers and found no statistical difference. Afterwards, student data was split into two groups based on their pretest data and how effective their inquiry questioning abilities were. Posttest results were then coded and compared based on science inquiry ability as it pertains to questioning and hypothesis-based approaches. The areas of interest were the questions asked by students and how students proposed that these questions could be answered. The researchers compared posttest results between the experimental and comparison group, as well as, the pretest results to the posttest results of the experimental group.

Students were found to have significantly improved in their ability to ask inquiry questions and develop hypothesis-driven actions to answer their questions based on the pre to posttest (Kang et al., 2012). The students who were in the lesser group based on questioning analysis were also found to have marked improvements in ability to ask questions. Another striking point is that the students of the experimental group were found to have greater
improvements when compared to the control group. Kang et al. claim that 72% of the experimental group were able to generate a higher-level inquiry question as compared to 52% in the comparison group.

A limitation of the study is in its focus on environmental health science, while another is the focus on only one school. Because the study specifically sought information on inquiry skills, it may have also been beneficial to analyze students throughout the learning process rather than just through a pre and posttest. Future investigations could seek to study the influence problem-based curricula has in different disciplines. It would also be worth looking into various other schools or social contexts to be able to generate a generalization.

Kang et al. (2012) concluded that most students increased their abilities in asking higher-level inquiry-based questions and seeking explanations for questions in terms of relations. They also sought out increased data collection and analysis to develop correlations and derive said explanations. Utilization of the problem-based curriculum was deemed as effective in developing inquiry skills and scientific literacy.

Going together with elevated inquiry-based skills is the idea that students are also becoming better critical thinkers. Not only are they learning how to properly ask questions that have open-ended responses, but they are also learning how to develop those open-ended responses. The necessity of data collection and analysis is also revealed with such learning.

A core component of problem-based learning is the fact that it stems from a real-world situation. The purpose is to increase relevance for students and make connections between concepts being taught. Once a real-world problem is posed, students are meant to embark on an
inquiry-type investigation where they ask questions, collect and analyze data, and develop evidence-based arguments to solve the problem.

Problem-based learning and real-world applications can increase student engagement and influence student understanding of a concept. These two approaches to science are imperative in utilizing context-based teaching. Much research has been conducted on the context-based approach in chemistry education, which is a higher-level science class. That said, little research has been conducted on context-based teaching in science during the middle years of a student’s education. King and Henderson (2018) sought to investigate the role of context-based teaching in the learning process of early high school students. The focus of the study was on learning that occurred when environmental science was taught in the context of a local creek.

King and Henderson (2018) studied a 9th grade science class in Australia over the course of an 11-week unit on environmental science. The unit was designed by the teacher of the class and revolved around a local creek. This unit required that the students embark on inquiry-based learning to assess the health of the creek. This involved the use of water quality investigations, data collection, and writing a scientific report. The high school of interest was a suburban high school containing mostly students from a middle socio-economic background. The average age of the students in the study was 13 years old and the students were of mixed genders.

Data collection involved an ethnographic approach, which meant describing behaviors, beliefs, and language of groups being observed (King & Henderson, 2018). For the purpose of this study, the class was split into two groups of varying abilities to allow for multiple focus groups. Because ethnography requires extensive observation, each lesson was attended, and videos and audio recordings were taken of the groups being investigated. Other sources of information included classroom work, interviews, and field notes. The data collection focused on
resonance, which is the ability of the student to make scientific connections to the context being studied.

King and Henderson (2018), found that student conversations showed evidence of resonance multiple times with the highest occurrences being in identifications of insects/animals. In the written responses, students exhibited resonance even more consistently with the highest occurrence being in flow rate of the creek, pollution, and identification of living things. Students were ultimately capable of successfully completing the writing task in the unit.

A limitation of the study lies in the limited scope of the focus groups. While the class investigated was split into two groups of varying ability, there was little to no variation in demographics of the class in terms of background. The school investigated was in Australia, which provides potential generalizations about students in well-developed countries. It would be beneficial to increase the population size and investigate context-based learning in various countries. Another consideration that may be useful in the future is studying students from various socio-economic backgrounds.

It was concluded that utilization of a context-based learning approach increased student engagement and interest (King & Henderson, 2018). It provided students with an opportunity to investigate a local landmark while promoting real-world relevance. A struggle with this approach may be the result of time constraints within class periods and the school year. It would be worth looking into for future teaching.

A significant finding is that students were able to make connections from the real-world to science in conversation and in writing (King & Henderson, 2018). It could then be concluded that increased resonance in student conversation translated to resonance in written responses.
Encouraging students to make these scientific connections may be difficult at first, but it appears to be worth the time and effort. Furthermore, it will help to build critical thinking and data analysis skills. With practice, students will be able to make connections on their own and collaborate effectively with their peers to develop conclusions and solve real-world problems. This is helpful in determining the best pedagogical approaches to science education.

**Inquiry Teaching**
Teaching strategies are often researched to determine their effectiveness on student learning and engagement. One such teaching strategy is the inquiry-based approach. According to Jiang and McComas (2015), inquiry teaching has been researched extensively; however, most of the research has been in research settings rather than in classrooms. As such, Jiang and McComas conducted a study to determine the different levels of inquiry teaching on student achievement and attitudes.

Inquiry teaching is a pedagogical approach to teaching in which students learn science concepts through the inquiry process or discovery (Jiang & McComas, 2015). It is a more student-centered approach and the teacher’s role is more as a coach or facilitator. Previous research has shown that inquiry teaching is as effective, if not more effective, that traditional methods for teaching. Jiang and McComas sought to examine these claims through propensity score analysis.

In order to conduct the study, the Programme for International Student Assessment (PISA) 2006 data was utilized (Jiang & McComas, 2015). This assessment is administered every three years and focuses on mathematics, science, and reading, with an emphasis on one of the three domains each administration. During the 2006 assessment, the emphasis was scientific literacy, thus creating a desire to utilize this data.
Three variables were studied: outcomes regarding students’ scientific achievement and attitudes, treatment regarding inquiry activities, and covariates, such as demographics and school characteristics (Jiang & McComas, 2015). Data was analyzed using propensity score analysis, which involves comparing variables without conducting physical research and randomizing said variables. In terms of outcomes, science competency, interest in science, and support for inquiry were considered.

Five levels of inquiry were established where the lowest level involved no inquiry and the highest level was considered an open inquiry with no teacher direction (Jiang & McComas, 2015). This data was collected from surveys given to the students. Because the PISA is administered in 57 countries, data was analyzed specifically for each country and then country data were compared.

It was discovered that in the United States, about 30% of students claimed they experienced the highest level of inquiry in their classrooms (Jiang & McComas, 2015). In contrast, 19% stated that they experienced the lowest level of inquiry. Furthermore, the data showed that the highest level of inquiry teaching (Level 4—the most open type of investigation) resulted in the lowest level of student achievement. The highest level of inquiry had a positive effect on student interest in science and support for inquiry. The highest level of student achievement was found in the middle level of inquiry teaching (Level 2), which includes students conducting activities and drawing conclusions but not creating investigations or asking questions.

Across countries, Level 2 inquiry was found to result in either the highest level of student achievement or the second highest level (Jiang & McComas, 2015). It was consistently above
Level 0 inquiry, which is mostly teacher directed teaching. Level 4 inquiry was shown to also increase student interest and support inquiry use.

One limitation of this study is its neglect to consider teacher responses to surveys. The perception of a teacher and a student may be different, especially as it pertains to the level of inquiry. For further research, an analysis that includes such data may be beneficial to get a better gauge of what levels of inquiry were being used in the classroom. It may also be worth investigating more recent assessment data. The 2006 PISA was selected specifically because of its focus on scientific literacy; however, 10 years may have an impact on the effectiveness of inquiry at different levels because of new research and strategies.

Jiang and McComas (2015) concluded the level of inquiry has significant effects on student achievement and perception of science. The middle level of inquiry fostered the greatest achievement as compared to the most open inquiry. This provides evidence for the importance of the role of the educator in the classroom. While open inquiry allows students to investigate freely, they may occasionally be hindered by that freedom and fail to investigate the concepts required. With guided or structured inquiry, the teacher could lead the students to where they need to be while also allowing them the freedom to make their own conclusions.

It was also concluded that increased inquiry can improve the attitudes of students towards science (Jiang & McComas, 2015). Inquiry teaching also varies depending on the teacher, students, and other factors. This means that understanding when, how, and when to apply various levels of inquiry is important in the classroom. Adhering to one style consistently may not be the most effective when it comes to different concepts. Therefore, it is imperative to consider the learning outcomes of the class, the time constraints, and other factors when implementing inquiry instruction.
Inquiry teaching is often said to increase student engagement and interest in science, address the decrease in students exploring science fields, and promote collaboration and scientific thinking (Gillies & Nichols, 2015). Because of this, inquiry teaching is being pressed in the education system and many educators are struggling to modify their pedagogical approaches to teaching. This is especially the case for primary school teachers who do not necessarily have the science background to promote the inquiry process.

The inquiry teaching approach may take professional development and time to build the skills necessary for successful implementation (Gillies & Nichols, 2015). This requires learning new strategies and customizing the classroom environment to fit the needs of the students. With that in mind, inquiry has its challenges and benefits. Throughout the process of pedagogical modification, teachers’ perceptions of inquiry may also change. Gillies and Nichols sought to investigate these perceptions, as well as the challenges and benefits of inquiry teaching.

In order to complete such an investigation, Gillies and Nichols (2015) conducted a study in which various teachers taught inquiry science units. Prior to the study, the focus teachers participated in professional development for four days in which they learned about the science inquiry units they would be teaching and cooperative learning strategies. The units being taught were about living versus non-living things and genetically modified food. Each unit moved at a different pace with lessons that implemented various inquiry techniques, such as research, data collection, and discussion.

The study utilized the interviews of 9 cooperating teachers who each taught sixth grade classes (Gillies & Nichols, 2015). The classes of interest were of similar socio-economic backgrounds in a large city in Australia. Six of the teachers were female, while 3 were male and none of them had previously taught science using an inquiry approach. Interviews for five of the
teachers were conducted individually and in pairs for the remaining four teachers. The interviews were semi-structured to allow for open-ended responses. Answers were grouped based on the common themes of teachers’ perceptions of inquiry science, the inquiry process, the role of cooperative learning, and the challenges of teaching science through inquiry.

It was discovered that teachers felt positively with their experiences teaching through inquiry, citing the effectiveness of open discussion. They enjoyed the freedom with which they could take the topics and relate them to the “real world” (p. 180). The teachers found the students to have increased interest and as a result, the teachers experienced greater confidence in inquiry science. Cooperative learning was found to increase student engagement and confidence with speaking. It also helped students to address misconceptions and learn concepts on their own. The challenges with inquiry learning were found to revolve around lack of science knowledge and resources or time.

One limitation of the study is its collection of data. The researchers only interviewed nine teachers despite more having gone through the professional development process before the study. This limits the field of responses. Furthermore, only interview data was collected. Observations may have proved beneficial in gathering evidence of cooperative learning and challenges of inquiry teaching.

Gillies and Nichols (2015) determined that teachers who utilized inquiry teaching had a positive perception of its strategies and outcomes. This was increased after constant practice and professional development. Professional learning opportunities can increase the confidence a teacher has in their knowledge and abilities to teach. This is due to the strategies that may be learned and the tools/resources that are often provided at such experiences.
Cooperative learning was also found to be a major contributor to the success of an inquiry-based environment (Gillies & Nichols, 2015). Being a scientist involves much discussion and collaboration. Without it, much of the theories and ideas in the world would not be as widespread. In the case of student learning, it can help to build communication skills while also helping students to develop the knowledge necessary to succeed and understand a topic.

While the study focused on sixth grade teachers, which may be considered elementary school teachers, it does have some implications at the high school level. One of the major implications is the importance of professional growth and reflection of the inquiry process. It takes time to develop and implement properly. Being patient and willing to struggle is common for teachers who begin utilizing inquiry. Also, discussion and collaboration are an important part of inquiry science at every level. Ensuring that fruitful discussions are occurring in the classroom is imperative for creating a positive learning environment.

One problem in today’s education system is a lack of interest in the fields of science, technology, engineering, and mathematics (STEM). This lack of interest has potential influences on the future of the workforce and advancements in science and technology. It is claimed that inquiry-based teaching approaches can be successful at addressing issues with interest and student engagement.

Literature often suggests that inquiry teaching is riddled with challenges, such as students’ lack of inquiry-based skills and lack time necessary to build them (Williams et al., 2017). It also claims that the teacher’s beliefs about inquiry, preparation, and skills play an important role in successful inquiry teaching. That said, inquiry-based teaching is said to increase student engagement and learning. Williams et al. sought specifically to investigate the influence of teacher beliefs and student perceptions of inquiry.
The investigation is a case study of one science teacher’s inquiry teaching experience over the course of two years in a New Zealand high school (Williams et al., 2017). During that time, the teacher taught students in years nine and ten who had an average age between 13 and 14. Prior to the study, the teacher had little to no experience teaching using inquiry-based methods. In order to learn how to implement inquiry the teacher attended workshops and collaborated with the researchers. Having done this, the teacher developed a curriculum that was inquiry-based and included the use of technology consistently.

Evaluation for the study was conducted through a variety of means (Williams et al., 2017). Planning documents and student work were assessed, while classroom observations and formal/informal interviews with the teacher and students were conducted. The purpose of using these sources was to develop an idea about changes in perceptions of the students and teacher, as well as engagement with inquiry and technology.

According to Williams et al. (2017), students enjoyed using technological tools for learning because of the ease of access for research. It was a challenge, yet enjoyable, to learn how to properly conduct research and present in unique ways as part of the inquiry process. Collaborative tools, such as Google Docs, where students can edit and share with each other were found to be useful. Although some would rather be taught through traditional teaching, the inquiry process was also said to be enjoyable compared to traditional teaching methods. From this process, the students were able to learn science topics and inquiry-based skills, such as problem solving, collecting and analyzing data, and discussing.

As for the teacher’s perspective, inquiry-teaching was frustrating at first, but as an understanding of the process was developed, it became easier (Williams et al., 2017). This development required modification of the teacher’s pedagogical approaches and scaffolding was
utilized to varying degrees. Once the students became responsive to a student-centered approach, less scaffolding was required and more facilitation was admitted, rather than direct teaching.

A limitation of the study is its focus on one teacher. While the evolving perceptions of inquiry teaching were at the core of the study, the research utilized only one teacher’s experiences. Further research could be done in other countries and with more teachers to gather their perceptions. Also, a larger student sample would enhance the study, which is possible through incorporation of more teachers.

Williams et al. (2017) concluded that teachers require ample time and support to develop the skills necessary for successful inquiry implementation. It is a process in which self-reflection is a must and constant research may be necessary. Inquiry teaching can also utilize much collaboration and doing so may enhance the teacher’s experience and learning. Technology implementation was also shown to supplement inquiry teaching and allow students to build the skills necessary for future research. It may require occasional adaptation due to loss of internet or dead devices, but technology can increase student engagement.

While teachers may not have a full grasp of inquiry teaching at first, students also will need extra support to become independent learners. Introducing short bursts of inquiry and independence was determined to be effective for student development and understanding of the process (Williams et al., 2017). Depending on the student abilities, scaffolding was found to also require variation to best accommodate.

This study can be thought of as reassurance for younger/newer teachers who may find themselves struggling. Especially for those new to the inquiry process, the conclusions exhibit the fact that teachers must be lifelong learners and willing to adapt. Students are willing to
change their attitudes and work habits so long as the teacher creates an environment and provides them with the necessary resources to do so.

**Crosscutting Themes**

Implementation of national learning standards promotes the use of experiences that cross disciplines (Chesnutt, Jones, Corin, Hite, Childers, Perez, Cayton, & Ennes, 2019). Utilizing such opportunities provides relevance for the material being taught and the ability to build skills that students may not be able to otherwise. This is specifically addressed in the “crosscutting concepts” of the Next Generation Science Standards (NGSS) (p. 303).

Chesnutt et al. (2019) state that an example of a crosscutting concept is “scale, proportion, quantity” (p. 303). This crosscutting concept could relate science to mathematics and even engineering. It can be argued that crosscutting concepts can benefit learning outcomes in science; however, this specific concept has not been explored in terms of its effects on science and mathematics outcomes on standardized assessments. Thus, Chesnutt et al. performed an investigation in order to determine the benefits of size and scale.

In order to develop an answer to their question, Chesnutt et al. (2019) studied a group of sixth grade students in an urban school in the southeastern United States. The population of the school was 50% white, 26% African American, 6% Hispanic, 3% Asian, and 5% other. Of those who attended the school at the time of the study, 52% qualified for free or reduced lunches. In all, 229 students participated in the study.

The research was conducted over the course of a 3-year period (Chesnutt et al., 2019). Data was collected at the beginning of the study and throughout its duration. The purpose for the longitudinal qualities was to see how student understanding of size and scale changed over time and how this affected their achievement in math and science. Students were assessed using a card
sort (arranging objects from smallest to largest) and a questionnaire on scale before and after sixth grade, and after seventh and eighth grade. Data was also taken from their End-of-Grade assessments after fifth, sixth, seventh, and eighth grade.

It was found that a significant influence on science and math achievement arose from students’ understanding of size and scale (Chesnutt et al., 2019). The influence was positive and while it was not a significant difference, there was a greater correlation between a student’s concept of scale and their science achievement than their math achievement. Furthermore, a difference was noticed in the correlation between students’ concept of absolute scale to achievement as compared to students’ concepts of relative scale. Despite this, both were found to have a positive effect on the science and math achievement of middle school students.

A limitation of the study is its focus on students from an urban school district. While the population of the school represents a variety of socioeconomic and ethnic backgrounds, it lacks the suburban and rural populations. This may have an impact on the sample being representative of the middle school population in the United States. It was also stated that some of the student data was not successfully collected over the course of three years (Chesnutt et al., 2019). This would have changed the sample size and may have had an impact on the results.

It was concluded that the crosscutting concept of size and scale does play a role in student achievement in the areas of math and science (Chesnutt et al., 2019). The significance is that it provides a steppingstone for further research on other crosscutting concepts and their role in science and math education. It can also have implications for research into engineering achievement and potential interest growth in science, technology, engineering, and mathematics fields.
Another idea suggested by Chesnutt et al. (2019) is that much growth and development occur for students between fifth and eighth grade. With that in mind, some of the students may have experienced greater achievement as they aged because of this development. Students can think more abstractly as they age.

That one crosscutting concept is shown to improve scientific and mathematical understanding is worth noting for educators in their quest to improve their practices. The NGSS is pushing towards three-dimensional knowledge, which can be daunting for specific topics and subject areas. This research provides support for such an approach to education. Understanding that the struggle to develop teaching strategies is worth it provides reassurance to new teachers, as well as those who must alter their practices.

Recent educational reform has pushed for a set of standards that includes not only concepts specific to the science, but also science and engineering practices and crosscutting themes (Fick, 2017). The introduction of the Next Generation Science Standards incorporates these three ideas, otherwise known as “dimensions” (p. 6). While this is innovative in terms of promoting inquiry, critical thinking, and self-sufficient learners ready for the 21st Century, there is some uncertainty in how the three dimensions can be implemented together to foster learning.

Research has been previously completed on the incorporation of disciplinary core ideas and science practices in science classrooms (Fick, 2017). It has also been completed on crosscutting concepts; however, the research was focused on specific concepts without examining how to support student learning of science through their usage. As a result, Fick developed a model to understand how to use the crosscutting concepts in conjunction with science ideas and tested it in his research. Fick specifically investigated how crosscutting
concepts could be used to support learning in development of students’ three-dimensional knowledge.

According to Fick (2017), the developed unit focused on the use of “Systems and models” (crosscutting concept) in alignment with “Earth’s Surface Processes” (disciplinary core idea), both of which were taken from a NGSS performance expectation (p. 9). Integration of the crosscutting concept was included as the frame for the unit since the focus was on watersheds as a water system. Secondly, the idea of systems was presented through examples in other disciplines during the last lesson.

The unit incorporated the use of 9 lessons over 16 class periods, which were tailored towards a middle school science class with students ranging from 11 to 14 years of age (Fick, 2017). Throughout the unit, different models, such as physical replicas of environmental features, were used to foster student learning. Students were able to develop their own models based on their understandings and modify them as new information became available.

As for the study, a single teacher was the focus as they taught the unit to classes comprised of sixth, seventh, and eighth grade students (Fick, 2017). The reason for this grouping of students was because the focus teacher was the only middle school science teacher at the charter school in which the study took place. The school was of mixed ethnic backgrounds with 72% being white, and the remaining 28% being comprised of African American, Asian, Latino, and multiethnic students. Overall, 70 students participated in the study.

According to Fick (2017), data was collected using a pre and a posttest. Students were also interviewed, and video recordings were taken. Throughout the study, the teacher was consulted in order to revise the curriculum daily.
Fick (2017) found that students performed significantly better on the posttest than the pretest. This result is specifically in reference to student understanding of the disciplinary core idea and crosscutting concept implemented throughout the unit. The video analysis showed that the crosscutting concept was discussed implicitly and explicitly. During implicit instruction of the concept, students were unable to develop a straightforward definition of a system. However, by the end of the unit and after explicit instruction, students demonstrated an increased understanding of systems.

A limitation of the study is its focus on one crosscutting concept and one disciplinary core idea. There are many disciplinary core ideas across age groups and determining how the crosscutting concept could address various core ideas could be beneficial. Another limitation is the fact that the focus group consisted of multiple aged students learning the same material. The reason for this is the differences in maturity level and academic ability. This may have had bearing on the material covered and the pace at which the class moved along.

It was concluded that a crosscutting concept was successfully implemented in a classroom to promote three-dimensional science knowledge (Fick, 2017). The implicit instruction of the crosscutting concept, while confusing for students at first, ultimately helped students to understand systems when it was explicitly taught. Therefore, using instructing the students about a crosscutting concept without their knowledge can be beneficial. Without it, students may have been unable to develop understandings on their own and think critically about systems.

This study proved that each of the three dimensions of the NGSS can be implemented in a science classroom. This is important for teachers to understand as they move forward with a
curriculum shift and browse potential teaching strategies. As for future research, more crosscutting concepts can be examined along with various methods of implementation.

Energy is a concept or theme found in all natural sciences. Because interdisciplinary concepts, such as energy, have a wide range of applications, they require much organization to promote student learning. As a result, they can often be confusing to students if presented improperly or in different ways. The Next Generation Science Standards seek to create a more coherent approach to the sciences in order to promote a smoother transition between disciplines with their various crosscutting concepts.

Opitz, Neumann, Bernholt, and Harms (2017) claim that the concept of energy is unique because it is addressed not only as a crosscutting concept, but also as a disciplinary core idea in the NGSS. Most research on teaching energy has focused on it as a disciplinary core idea. Furthermore, energy has not been specifically analyzed in terms of student understanding as they progress through different science courses. Opitz et al. investigated the connection between students’ progressing understanding of energy and science disciplines. They also investigated how this relationship changes as students learn more about energy through middle school.

In order to conduct this investigation, Opitz et al. (2017) analyzed data from sixth, eighth, and tenth grade students who learned about energy in different science classes. The classes of focus were biology, chemistry, and physics. The sample population consisted of 742 students from many different classes in an urban setting in Germany.

The data collected was from a multiple-choice instrument and it allowed the researchers to develop three overlying scenarios that detailed students’ progression in energy understanding (Opitz et al., 2017). The first involves a progression of energy in which connections are made
between the three sciences across all grade levels. The second discusses energy as having a different focus depending on the discipline. The third process incorporates more integration where a cross-disciplinary understanding of energy is developed. These scenarios were then compared using confirmatory factor analysis.

It was discovered that students’ energy understanding across disciplines did change between sixth and tenth grade (Opitz et al., 2017). It was also found that the preferred model for each grade level was that of cross-disciplinary understanding of energy.

A limitation of the study is its focus on three specific grade levels with a gap in between. Depending on the student, science may be taken from middle school all the way through high school, which could have some influence on the understanding of energy as a student develops. The study was conducted using data collected in Germany, which likely has a different method for implementing science courses. Further research could be conducted in other countries and using different grade bands.

A major conclusion derived by Opitz et al. (2017) is that students develop a single, cross-disciplinary understanding of energy as they progress through science. This is contrary to what was initially expected prior to the investigation. Student understanding of energy was shown to increase over time and while this occurs, they develop additional conceptions of what energy is. In general, students do not actually see energy as different across disciplines, which may or may not be true for every student.

Energy is a concept that requires student understanding in a cross-discipline sense. While it must be well connected across sciences, there are foci for energy that are specific to each discipline. Utilization of these foci can help students to develop a better understanding of energy,
in general, and its role in the world. Other ways to promote the understanding of energy are to ensure that terminology is consistent in various science courses and make connections to other disciplines. This is significant for student growth and knowledge in three dimensions.

Because it was shown that an understanding of energy can be learned early on, it is possible that other crosscutting concepts may be learned in a similar fashion. The key in continuing this learning trend would be to treat the concepts similarly to energy: keep terminology consistent and make connections to other disciplines whenever possible. Informal research could be conducted in classes as implementation of the NGSS increases across school districts. The benefit of this would be to understand how other science classes are teaching the crosscutting concepts. This knowledge will help to modify instruction for the benefit of the students in developing the skills and understanding they need to succeed.

**Research Support for Capstone Project**

**Argumentation**

Scientists consistently communicate their research results and other scientific ideas through discussion, inscriptions, or written word. Collaboration with peers about evidence-based findings is known as argumentation (Kern & Crippen, 2017). This is an integral aspect of science and without it, many ideas would have been lost. As such, students are taught to use communication skills in order to participate in argumentation so they may learn and retain knowledge.

According to Kern and Crippen (2017) the use of collaboration and discourse is claimed to be beneficial in cyberlearning environments. Further support and learning are said to be provided by technological-based scaffolding; however, minimal research is present on specific scaffolding strategies in a technology-based classroom. Because of this, Kern and Crippen
sought to study the influence of two specific scaffolding strategies for argumentation and inscriptions (graphs, diagrams, and other types of data) on student learning.

Kern and Crippen (2017) specifically investigated how inscriptions paired with self-explanation prompts and faded work examples (as part of argumentation) influence the acquisition and retention of knowledge. For the purpose of the study, a self-explanation prompt refers to the process in which a student engages in internal discourse about a topic while solving a problem. Faded work examples refer to completed solutions to problems where some pieces of information are missing, and the learner is meant to fill them in.

In order to complete the study, a quasi-experimental design was used (Kern & Crippen, 2017). Participants were placed in one of four categories, which were based on the provided instruction. The control group was taught a lesson in which neither scaffolding strategy was used, while the experimental groups fell into the remaining categories. Those participants were taught a lesson that used either self-explanation prompt usage or faded work examples, or both strategies.

Participants were from a large suburban school in the southwestern United States (Kern & Crippen, 2017). Most of the population was white with 41% coming from minority ethnic backgrounds. Of these students, 17% qualified for free/reduced lunches and 8% had documented disabilities. The courses of focus were General Biology, Honors Biology, or Inclusionary Biology, which crossed four total teachers. The total number of participants was 245 students who were in ninth and tenth grade with an age range between 13 and 16 years.

Data collection involved the use of a pretest taken one week before the experimental phase, a posttest taken immediately after the experimentation phase, and a delayed posttest taken
five weeks after the experimental phase (Kern & Crippen, 2017). During the experimental phase, students were taught using the various methods of study over the course of five 50-minute classes. The pre- and posttests were developed using content knowledge items from the focus school district, the Program for International Student Assessment, the National Assessment of Educational Progress, and the American Association for the Advancement of Science assessments. Upon completion, the content knowledge tests contained questions requiring students to answer a question and supply a reasoning for their response.

The teachers were interviewed about student use of the provided scaffolds/activities and whether student engagement took place (Kern & Crippen, 2017). It was found that engagement was high, and students needed minimal teacher help. Furthermore, the results indicated that there was no significant difference for the combined condition, the self-explanation condition, or the faded work example over time. There was a significant increase in performance on the posttest immediately following the experimental phase. The delayed posttest, on the other hand, contained improved performances, but they were not as high as the original posttest.

As for limitations of the study, the authors indicated that multiple disruptions to the learning environment occurred throughout the experimental phase and during the posttest (Kern & Crippen, 2017). As a result, many students were omitted from participation of the study as they did not take the posttest. Also, the assessment tools were developed based on students with upper level test-taking skills and competency. Some of the participants had documented disabilities and English language learners, which could have influenced the test performance scores.

It was concluded that more research must be done on research-based theories being used in natural learning environments (Kern & Crippen, 2017). The issue lies in the lack of
authenticity in developing said educational theories. Generalizations may also not be possible depending on the focus population. Kern and Crippen mention that college students are more prepared for self-sufficiency in the classroom, whereas general high school students are still building those skills. This may have influenced their ability in using the different scaffolding techniques.

The study also implies, however, that argumentation and the usage of inscriptions are effective tools for teaching concepts. While delayed posttest scores were not as high as the original posttest, they were still higher than the pretest, which indicates retention of science knowledge. With that in mind, students showed improvement after completing an inquiry-based cyber learning segment that contained scaffolding strategies in it on top of those in this study. This suggests the positive influence of inscription and argumentation in science and a need for continued research.

It could be argued that the most important part of science is argumentation. It allows scientists to connect laboratory work and data to the thought processes that result in new ideas and theories (Osborne, Henderson, MacPherson, Szu, Wild, & Yao, 2016). It is for this reason that argumentation has become a part of the foundation of the Next Generation Science Standards. Without it, students would not build the skills necessary for scientific thought and becoming productive members of society.

According to Osborne et al. (2016), argumentation has been shown to support student understanding of science concepts; however, it is rare to see students asking questions and justifying their thoughts. This rarity may be because argumentation is a difficult skill to master. Furthermore, little research has been conducted on assessing student ability with argumentation.
As such, Osborne et al. sought to develop a learning progression for argumentation and test its validity.

Osborne et al. (2016) postulate that argumentation is the ability of a student to resolve claims through critique. After consulting the literature, a learning progression was hypothesized. The final learning progression was comprised of three major levels with varying degrees of connection between claims and evidence known as warrants. The lowest level involves identifying a claim or evidence. A student who can identify a both a claim and evidence and explain how they are connected demonstrates the second level of argumentation. The highest level requires being able to compare claims, evidence, and warrants while also demonstrating an ability to critique arguments. It was hypothesized that students would have more difficulty demonstrating competency with higher levels in the learning progression.

The study on the hypothesized learning progression was conducted in a large school district in the San Francisco Bay Area (Osborne et al., 2016). Its focus for the purpose of this paper was on 803 middle school students. In addition, another 16 students were interviewed with a set of argumentation test items. Throughout the study, the content of focus was on the “structure of matter” (p. 829).

In order to collect data, students completed assessments in which the items were meant to evaluate argumentation ability (Osborne et al., 2016). Items were developed based on specific criteria, such as inclusion of a scientific question, hypothetical evidence, and arguments addressing the question. Students also participated in think aloud interviews. The data was analyzed using a Rasch analysis.
Osborne et al. (2016) discovered that the hypothesis was supported meaning that the lowest level of the progression was deemed easiest by the students and the highest level was the most difficult. It was also found that students had more difficulty with developing warrants when they were associated with scientific concepts rather than a general context. Osborne et al. postulate that this may be due to a lack of science knowledge, but it is possible that other factors may have played a role. Lastly, older students demonstrated a higher competency with argumentation and being able to complete tasks to the highest level of argumentation.

A limitation of this study is the lack of argumentation in a social context in the classroom. Rather, the assessments evaluate whether students can show argumentative thought. That said, being able to engage in argumentation through writing is one job of a scientist. Another limitation is the focus on the cognitive aspect of argumentation and the neglect to acknowledge socio-cultural impacts on argumentation ability.

The main implication from this study is that it can be used to develop a sequence for introducing argumentation in the classroom (Osborne et al., 2016). This can be done over the course of one class, as well as over the course of progressing science classes. The idea would be to start with identifying parts of an argument, work towards connecting them, and then to begin critiquing and analyzing the different aspects of an argument to develop or refute one. Scaffolding could then be applied as needed to support argumentation skill development.

As for assessments for argumentation, Osborne et al. (2016) concluded that constructed-response questions were more effective at assessing argumentation competency than multiple-choice questions. Furthermore, increasing the number of claims and pieces of evidence for students to analyze increases the difficulty of assessing questions. Scaffolding can be beneficial
in helping students to understand what is expected as a response. One example would be to use a sentence starter.

Critique is often utilized in humanitarian classes and is rarely used in science (Osborne et al., 2016). With that in mind, this research suggests that teaching critiquing skills is a necessity. Not only is it a part of the argumentation process, but it is a significant part of everyday life. Learning how to critique in different domains is beneficial for students of all ages.

While engagement in argumentation has been shown to be beneficial for student understanding of concepts, little evidence is known about teachers’ knowledge of argumentation (Sampson & Blanchard, 2012). Argumentation is rarely used in science classrooms, implying that teacher knowledge of argumentation of knowledge is low or that they lack the necessary resources for implementation. That said, an initiative has been made to increase the available resources for teachers, such as curricula and instructional strategies.

With the introduction of a new initiative, expectations for teachers are increased as they are required to learn and understand what they are teaching. This may also involve altering their classrooms and familiarizing themselves with new strategies. Since little is known about teachers’ perceptions and argumentation understanding, Sampson and Blanchard (2012) completed a study to questions surrounding these ideas.

Sampson and Blanchard (2012) sought to answer a few descriptive questions in their research, each focused on the teacher and argumentation. The questions involved science teachers’ evaluation of alternative explanations for phenomena, the characteristics of science teachers’ arguments in support of phenomena, views on integration of argumentation, and whether arguments were constructed, and argumentation viewed differently based on
background and context. Because of the nature of the questions, interviews and qualitative data analysis techniques were used to collect and analyze data.

The focus teachers for the study were recruited from a large public secondary school district in the southeastern United States (Sampson & Blanchard, 2012). The district itself houses over 30,000 students of varying ethnicities. Of the population, 49% of students were white, 41% were black, 3% were Hispanic, and 3% were Asian. The economically disadvantaged population made up 32% of the population, while 17.2% were classified with disabilities, and 1% were English language learners. The 30 participating teachers had a range of experience with the least being 1 year and the most being 26 years. The science backgrounds varied and the teachers either taught middle or high school for one of the schools in the district.

In order to collect data, a cognitive appraisal interview was utilized (Sampson & Blanchard, 2012). With this type of interview, subjects are provided a problem, asked to solve it during a period, and then asked about their reasoning and strategies. In the case of this study, the provided problem involved determining the validity of alternative explanations for a natural phenomenon. After determining the most valid explanation, the teachers were tasked with developing and writing an argument to support the chosen explanation. Lastly, the teachers were asked to describe his or her beliefs about the value of such a technique in a secondary science classroom. The analyzed data included field notes, the transcripts from the interviews, and the written response.

Sampson and Blanchard (2012) determined that teachers decided the validity of explanations using three major techniques: based on what they teach their students, using elimination, or through data analysis. In order to explain their thought processes, the teachers resorted to expanding on the explanation, using data as support, pointing out why the other
explanations were wrong, and creating a series of truths to develop an explanation. Teachers then demonstrated an appreciation for argumentation because it requires students to think critically, it teaches about the inquiry process, and it can help students understand content; however, not all teachers made these claims. Similarities were also found in the teachers’ analysis methods, reasoning, and thoughts on argumentation based on their science backgrounds.

A limitation of this study is its use of only 30 secondary school teachers in a city district in the southeastern United States. Further research could utilize data from teachers of various regions in the United States or world with different content and age specialties. It would also be worth noting the diversity of the teachers themselves. While the demographics and backgrounds of the students were mentioned for the district studied, Sampson and Blanchard (2012) fail to mention the demographics of the teachers themselves. Another aspect of the study that calls for further research is its focus on qualitative data. Utilization of quantitative data would provide increased support for claims.

One implication of this research is that teachers may find themselves resorting to prior knowledge or personal beliefs in order to refute or support a scientific explanation, which does not align with scientific habits. Therefore, a shift must occur from the standpoint of the teacher. In order to successfully teach students proper argumentation techniques, teachers must first learn to utilize said techniques effectively themselves. This begins with learning them properly in traditional science classes and in higher education courses meant for pre-service teachers. Furthermore, professional development would be useful for in-service teachers who were not exposed to argumentation during their education.

It was also mentioned that some teachers were concerned with student ability and the necessary resources to build argumentation skills (Sampson & Blanchard, 2012). Professional
development can be useful in addressing these needs as well. Teachers may need to learn scaffolding techniques for building argumentation skills, which can help overcome a student ability barrier, thus creating a need for development classes.

Lastly, an initiative to increase argumentation in science requires that all teachers be on board with its implementation. That some teachers do not appreciate or believe in its usefulness can prevent forward progress (Sampson & Blanchard, 2012). This produces a need for constant support from administration and persuasion from fellow teachers to push for increased argumentation.

Over the past decade, a focus has been placed on implementing argumentation in the science classroom (Yilmaz, Cakiroglu, Ertepinar, & Erduran, 2017). Argumentation is argued to increase student understanding of concepts and how science knowledge is developed, thus the significant rise in attention to its usage. For argumentation to be made a focus in science education, pedagogical practices must be considered and modified to provide the necessary resources for successful implementation. One such way to learn these strategies is through professional development.

Because it has been stressed in recent years, research is leaning towards investigating the practices utilized by teachers to increase argumentation with the goal of identifying useful strategies. Yilmaz et al. (2017) sought to analyze the instructional strategies that teachers implement in their classrooms for the purpose of argumentation. Specifically, they wanted to discover what strategies teachers use when they plan and implement classroom practices related to argumentation.
Yilmaz et al. (2017) performed a study on individuals taking a graduate level course in Turkey. The course was available for students of the university, as well as already working teachers. Its purpose was to enhance science teachers’ theory and teach argumentation pedagogy. The class was comprised of seven students, three of which were science teachers. The other four were graduate level students. As part of the course, the students developed argumentation-based lessons and implemented two in classrooms. Those who were already teachers taught the lessons to in their classrooms while the other students gained permission to teach their lessons at cooperating schools. The age groups of the classrooms varied from elementary to high school; however, demographics were not considered for this study.

Qualitative data collection methods were used throughout the study with the intent of directly determining strategies used to spark argumentation in the classroom (Yilmaz et al., 2017). This included analyzing video-recordings of the lessons, interviews, self-reflection papers, lesson plans, and student worksheets. In order to analyze the data, Interpretive Content Analysis was used, which involved coding the sources of data and identifying interactions that resulted in argumentation or its justification.

It was discovered that the instructional strategies utilized fell into one of three categories: basic instructional strategies for argumentation, meta-level instructional strategies, and meta-strategic instructional strategies (Yilmaz et al., 2017). For the purposes of this study, basic instructional strategies refer to those in the lesson plans and practices used to begin or promote argumentation. Meta-level strategies are also found in lesson plans and practices but require more planning and higher-level thinking to implement. Lastly, meta-strategic instructional strategies are concerned with the guidelines behind an argument, generalizing and expressing when and why a specific thinking strategy should be used.
This research is limited by its number of participants and the fact that each represents a different discipline and age group. In order to further study the focus question, a wider group of participants should be studied. They could also be compared based on discipline and age group to determine whether any patterns emerge in the strategies used. The focus group also consisted solely of individuals who were in a specific graduate level class. This further limits the study to individuals learning specifically about argumentation rather than those in the field with or without formal education on the topic.

It was concluded that each of the studied individuals utilized a diverse set of strategies that promoted a range of abilities (Yilmaz et al., 2017). Most notably, the subjects taught using strategies that not only required a basic understanding of argumentation, such as constructing an argument, but they also taught students how to develop counterarguments and refute claims. This is important in teaching students how to think critically. The teachers were also able to convey the importance of understanding how argumentation works and why it is important to incorporate evidence and justification. These conclusions provide evidence that receiving formal education or professional development in argumentation practices is beneficial for its implementation in science classrooms.

Yilmaz et al. (2017) specifically investigated the types of strategies that are being used to increase argumentation in the classroom. One thing they did not investigate was the effectiveness of these strategies. Doing so would be the next step in furthering their research. Specifically, a study could be completed on the retention of science knowledge, understanding of the nature of science, and the development of argumentation skills.
Nature of Science
The Next Generation Science Standards are placing an emphasis on both science and engineering practices (Herman, Clough, & Olson, 2012). It could be argued that for students to effectively utilize and understand both disciplines, they must develop knowledge of the “nature of science” (p. 272). The nature of science is used to describe what science is and is not, how scientists work, and how science and society influence each other, among other ideas. Because it plays an integral role in understanding science concepts and real-world applications, nature of science instruction is a goal for science classrooms.

The nature of science has been increasingly researched over the last few decades (Herman et al., 2012). Despite this, one issue combating the nature of science is that it is not heavily implemented effectively, if at all. This could be due to its complexity and some pre-service teachers do not receive ample instruction in its instruction. As such, Herman et al. sought to study how the nature of science is implemented by teachers who graduated from a rigorous secondary science teacher education program. They also wanted to determine how much they align with or go beyond what was taught in the program.

In order to complete this study, Herman et al. (2012) selected graduates from a two-year (four semester) science education program that placed an emphasis on the nature of science instruction. The program itself consisted of school observations, an internship, a student teaching placement, and multiple pedagogy classes. The study consisted of 13 participants who were at least in their second year of teaching.

Data was collected qualitatively in order to analyze the teaching methods of the 13 participants (Herman et al., 2012). Observations were conducted and field notes were taken, and instructional materials were collected. The participants also completed a Likert Scale
questionnaire to determine the teacher’s understanding of the nature of science. Analysis of the data was completed using a 1-5 scale that rated the degree of nature of science instruction with 5 meaning most reflective of nature of science instruction. This was a method for coding the data and allowing simplified analysis.

It was found that 4 of 13 participants were high nature of science implementers, 5 implemented it to a medium degree, and the last 4 implemented it to a low degree (Herman et al, 2012). Three out of the four low-level implementers did use practices modeled in their training program. The observations and collected tools were consistent with each other in terms of the nature of science scores. Participants demonstrated struggles with taking advantage of opportunities to cover the nature of science during discussion or presentation of content. They also had a difficult time connecting the same nature of science ideas in multiple contexts.

One limitation of this study is its focus on a mere 13 participants from the same secondary education program. This limits the development of generalizations across secondary science teaching programs and their effectiveness with the nature of science instruction. Further studies could seek to investigate different pedagogical approaches to the nature of science and their use by teachers after completing a secondary science program. Generalizations could then be made on which approaches are effective for instructing pre-service teachers.

It was concluded that the level of nature of science understanding had no effect on the implementation of the nature of science in the classroom (Herman et al., 2012). However, that is not to say that understanding the nature of science is not necessary in order to teach it effectively. The four teachers who had a high occurrence of nature of science teaching were well versed in the topic. There was also no relationship between the number of service years and the level of implementation of the nature of science.
One important takeaway is the idea that implementing the nature of science does require planning; however, it is also important to have lesson structures that allow for it to be brought out authentically. Opportunities may arise where it can be discussed without it having been planned. Being prepared to discuss the nature of science when the situation presents itself is important. Thus, the study provides the evidence for being adequately instructed in its usage.

While there is little to no empirical evidence, the nature of science is said to increase student understanding of science concepts (Michel & Neumann, 2016). Based on theoretical assumptions, this is often because of its ability to connect interrelated ideas. As such, utilizing instruction that incorporates the nature of science can be an effective method for instructing students.

Another viewpoint of the nature of science is that it plays a significant role in developing epistemic ideas of science (Michel & Neumann, 2016). Unlike the influence of the nature of science on learning concepts, its role in epistemic ideas has been studied. Because there is little empirical evidence of the nature of science’s positive influence on scientific knowledge retention, Michel and Neumann desired to provide such evidence.

Michel and Neumann (2016) decided to specifically investigate the role the nature of science plays in understanding energy concepts. The reason behind this is the challenges energy poses to many students. It also contains epistemological aspects that can be utilized in its instruction. Michel and Neumann sought to answer a question asking how students’ understanding of the nature of science related to their learning about the nature of energy as well as their acquisition of physics content about energy.
Completing this investigation involved the study of holiday science camps, each of which lasted three days (Michel & Neumann, 2016). Overall, 82 students participated in the study and 26 of them were females. The students were from 6th and 7th grade and lived in Germany where the camps took place. Students were divided into two groups and taught identical units on energy. The difference was in supplemental instruction provided to each group. The first group received instruction on the nature of science before being taught the energy unit, whereas the second group received an additional unit of energy instruction. In doing so, the students each received the same amount of instruction.

Data collection involved assessing students’ understanding of the nature of science, understanding of energy as a theoretical concept, energy content knowledge, and other control variables (Michel & Neumann, 2016). These were assessed both prior to and after the energy unit of focus. In the case of the second group, this meant providing the assessment in between the first and second energy units. The control variables analyzed in the case of this study were interest in physics, motivation, and cognitive abilities. In order to analyze the data, the results of the assessments were coded and used to develop regression models for comparison. Reliability measures were utilized and found to conclude that the tools were acceptable.

It was found that both groups achieved similar learning gains in the nature of energy as a theoretical concept (Michel & Neumann, 2016). Students with a higher nature of science score were found to have an increased gain in understanding the nature of energy. The same trend was noticed with content knowledge increases; however, there was no significant difference between the two groups and their gains. Lastly, a learning increase was exhibited in the content knowledge of energy.
A limitation of this study is its focus on energy as a concept. Energy is only one sample of the physics curriculum, which is a small part of the whole idea of science. Further studies could be completed on different concepts and different disciplines to see relationships between the nature of science with these. Another is the short period of time that the students were engaged with the material. The unit only lasted a total of 270 minutes, thus requiring some materials and practice to be condensed for optimal coverage.

It was concluded that the concept of energy may be viewed differently based on the level of nature of science knowledge an individual possesses (Michel & Neumann, 2016). Those who had lower levels of understanding of the nature of science demonstrated learning the concept of energy at a slower pace than those with higher levels of understanding. The understanding of the nature of science also had a small positive correlation with students’ cognitive abilities. Based on this information, it could ultimately be concluded that understanding the nature of science influence science learning for concepts requiring more general knowledge about the nature of science and higher-level concepts. As such, this study demonstrates a need for further empirical research on the nature of science and its influence in student learning; however, it does provide a reference point for such studies.

**Reasoning**
One characteristic of science that is often forgotten is argumentation, which is one of the components of science that allows for social interaction. As a result, students are often considered to lack argumentative reasoning skills. Recent studies provide evidence for this claim and educational reform seeks to amend this shortcoming, especially in the United States (Cavagnetto & Kurtz, 2016).
It could be argued that students are not actually lacking in argumentative reasoning skills but that argumentation reasoning is reliant on contextual factors (Cavagnetto & Kurtz, 2016). Thus, students who are perceived as having minimal reasoning skills when they fail to develop a logical argument may actually not be able to translate their knowledge due to environmental influences and the framing of the task at hand. Because the research on the view of contextual influence is limited, Cavagnetto and Kurtz sought to investigate it.

Cavagnetto and Kurtz (2016) wanted to specifically study whether argumentative reasoning could be enhanced through modification of contextual cues and removal of unnecessary information in prompts. Completing this investigation involved conducting two experiments. In the first experiment, a quasi-experimental design was used to determine the effect of specific cues, such as defined directions, explicit language, and diminished irrelevant information on reasoning ability. In the second experiment, a randomized design was used to analyze the effects of using a broad versus science-specific context on reasoning ability. In both cases, participants were asked to sort a set of notecards containing reasoning patterns into two separate groups based on their rationale.

In Experiment 1, a sample of 88 undergraduate students from a large state university was used (Cavagnetto & Kurtz, 2016). The population consisted of juniors and seniors from a variety of majors. Of the participants, 63% were female and 37% were male. Experiment 2 contained similar demographics; however, only 74 students participated in the experiment. Experiment 1 data was analyzed using a chi-square analysis, whereas a two-tailed t-test analysis was used in Experiment 2.

It was found that in Experiment 1, 27% of participants in the control group correctly sorted the notecards and provided adequate rationales (Cavagnetto & Kurtz, 2016). Those who
received specific cues for their instructions, on the other hand, correctly sorted the notecards 48% of the time, which was deemed to be a significant difference. In Experiment 2, participants whose prompts utilized an everyday context completed the task 50% of the time, which was also a significant improvement. That being said, results did not indicate whether one technique for assessing argumentative reasoning was more effective that the other.

A limitation of this study is its focus on the undergraduate student population. The students in the study were upperclassman and had experience with college for more than two years. Their reasoning ability and knowledge base is different than it was at a high school level. Because educational reform is altering science classrooms at each level, further research could be done to investigate contextual cues in high school settings. This would provide a more accurate depiction of their influence on students in their late teenage years.

According to Cavagnetto and Kurtz (2016), it was concluded that strategically wording cues and reducing the amount of unnecessary information in instructions can increase the ability of a student to recognize different reasoning patterns. Because the students were able to demonstrate an ability to reason, it can be argued that students are not lacking in these skills. Furthermore, the results of the experiments support the idea that students’ reasoning ability may be dependent on contextual factors.

The results of this study also suggest implications for classroom patterns of argumentation. Student performance with argumentation and even engagement may be influenced by a variety of factors that can be modified. While a student may not demonstrate adequate reasoning or argumentation skills, it does not mean that they do not have the knowledge to do so. The key in developing teaching practices is in finding cues to help access that knowledge. An idea that can be pulled directly from the study is related to instructions and
questions. In a classroom, it would be beneficial to ask questions and provide instructions in a manner that is succinct yet explains or asks for the proper information.

It is often argued that student struggle to remain interested in science. This is attributed to various reasons with lack of real-world application and rote memorization at the forefront (Waldrip & Prain, 2017). Ensuring student learning and increased development is now said to happen as the result of increased engagement in argumentation and scientific reasoning. Much research has been conducted to continue studying the effects of scientific reasoning on student learning, as well as strategies for increasing scientific reasoning abilities.

One failure of teachers is to allow for student creativity in building their reasoning skills (Waldrip & Prain, 2017). Scientists are claimed to engage in intuitive thought experiments and explore new representations of ideas. This is an example of creativity in the field of science and providing students the opportunity to recognize this is significant for increasing their value of scientific thought. Waldrip and Prain sought to develop a framework for characterizing students’ creative reasoning processes and apply it to assess teachers’ practices to support reasoning. They also wanted to identify the effect on student engagement and establish implications for teachers engaging students in science learning.

Waldrip and Prain (2017) constructed a framework that utilized five creative attributes (inquisitive responses, persistence, imaginative responses, collaboration, and discipline-based responses), as well as incorporated ideas that students’ creative reasoning is comprised of linguistic, spatial, and visual reasoning. They then collected data from four classes of students taught by two different teachers (each taught two classes). The classes were made up of about 25 middle school students. Each teacher was instructed to teach through engaging the learners in
reasoning activities that were student-centered. The study followed a case study format in which specific topics were followed for a period of time, such as isotopes and half-lives.

Data was collected using videos, surveys, and student interviews (Waldrip & Prain, 2017). Two video cameras were used in each class to focus on different subjects. The first camera focused on the teacher while the other focused on a different student group in each class. They specifically captured student conversations, drawings, and activity. Analysis was centered around finding common themes and identifying important sequences throughout the lessons. Overall, 4 students from each class, for a total of 16 students, were interviewed. The purpose behind the interviews and surveys was to develop an understanding of student perceptions of engagement in science learning.

It was found that the teachers regularly invoked student inquisitiveness between 20 and 28% of the time (Waldrip & Prain, 2017). This inquisitiveness was also linked to imagination. While neither of the teachers were informed about the framework, they both prompted students to express each of the five major qualities. Students even proposed explanations and asked questions that the teachers did not anticipate, thus driving the learning in directions prompted by the students themselves.

A limitation of this study is its focus on two teachers and four classes. This limits the participant population, as well as the variation in teaching strategies that are utilized. While the two teachers may have different philosophies and incorporate different strategies for invoking student reasoning, studying a wider range of teachers would allow for further analysis of data. Furthermore, the focus was solely on middle school students. Widening the age range and allowing for different disciplines may also yield different results.
Waldrip and Prain (2017) concluded that student perceptions of engagement in science learning was positive. The students believed that throughout the reasoning process, they were learning from each other, which is significant in terms of the worth of promoting student reasoning. One of the main reasons that students learned from each other is that the teachers refused to provide answers outright; they wanted the students to think for themselves. This forces the students to struggle and get creative with their thought processes and analyses of presented situations, thus confirming the idea that development and reasoning ability does not occur without being challenged.

Engaging students in science learning and the reasoning takes careful planning and constant evaluation of student needs (Waldrip & Prain, 2017). Ensuring that the questions are conducive to critical thinking yet not too challenging to dissuade students is imperative. Also, allowing students to ask questions and direct learning can help students to feel empowered. In building these techniques, students will be able to develop their scientific reasoning skills along with an appreciation for real science.

A significant portion of science involves reasoning to develop claims or theories based on evidence. It could be argued that traditional science classrooms fail to invoke this type of skill in students and instead promote rote memorization of concepts. One aim of the Next Generation Science Standards (NGSS) is to bring reasoning back into the science classroom (Liu & Lawrenz, 2018). The purpose behind this is to build cognitive skills and interest in students using real-world science.

Previous research has been conducted on scientific reasoning; however, the focus has not been on the cognitive foundations behind how people reason. Most investigations have been based on the act of reasoning or the context in which it is used. As such, Liu and Lawrenz (2018)
wanted to study the cognitive processes that occur during reasoning. They specifically
investigated college students and what cognitive patterns are exhibited as they reason about
various arguments.

In order to conduct the investigation, Liu and Lawrenz (2018) studied 26 undergraduate
students from a university in the Midwestern United States. Theoretical sampling was used to
gather the most random grouping, which ultimately consisted of 26 participants of varying
ethnicities and majors. Most participants were Caucasian and 20 of them were females. Majors
explored include kinesiology, elementary education, and art, among others.

Data collection involved the use of an interview after participants read a few articles on
opposing viewpoints in Global Climate Change (Liu & Lawrenz, 2018). The topics of focus were
Earth’s temperature change, rising sea level, and extreme weather events. Participants read the
articles aloud sentence-by-sentence, stating their thought processes after each. Upon completing
the articles, participants were asked a series of questions that assessed prior knowledge,
evaluation of the arguments, and personal beliefs. The interviews were recorded and then
transcribed.

Analysis of the data was done through a coding system (Liu & Lorenz, 2018). It was
determined that the participants had a limited understanding of Global Climate Change issues
from prior learning. They also exhibited three patterns of reasoning: minimum reasoning,
constrained reasoning, and deliberative reasoning. The participants utilized each of these
reasoning patterns to some degree. Minimum reasoning was made evident when individuals had
simple reactions to the arguments presented (simply agreeing or disagreeing), and when they
sought to confirm their own beliefs using the arguments. Constrained reasoning entails fixating
on superficial writing details and numbers for factual information, challenges in understanding
the relevance of ancient events, and reflecting on their own knowledge and beliefs. Deliberative reasoning involves distinguishing between correlation and causation and considering statistical conclusions and alternative conceptions.

The study is limited by its focus on undergraduate students and its sample size. While the participants in the study were random and actions were taken to ensure a representation of the population, each participant was from the same university and there were only 26. The average age of the participants was slightly over 19 years implying that many were in their first two years of college. As a result, they might not have the experience or maturity of a college senior, but they do still have experience that a high schooler would not. This may have some bearing on the cognitive processes being developed and ultimately assessed. Future studies could follow the same research at different age groups.

Liu and Lorenz (2018) concluded that individuals tend to only look for evidence supporting their own beliefs and fail to piece together differing perspectives to make an argument. It was also determined that the patterns of reasoning aligned with dual-process theory and its systems of thinking based on prior knowledge, personal beliefs, and effortful reasoning. Minimum reasoning aligns with System 1, deliberative reasoning aligns with system 2, and constrained reasoning exhibits parts of both systems.

It can be further concluded that students of all levels experience difficulties with reasoning (Liu & Lorenz, 2018). This is important to consider for high school classrooms that are beginning to introduce reasoning skills. At this point in time, students may or may not have previously been exposed to reasoning in previous years. As such, it is imperative to understand that building reasoning skills takes time, patience, and practice. Students may require support at
first, but as reasoning becomes a typical practice in the classroom and across disciplines, they will be able to become more self-sufficient.

**5E Model**

Students will often enter a science classroom with misconceptions or alternative conceptions about scientific concepts. For teachers, these can be a challenge to address and ultimately change. One approach that is said to be effective in completing such a task is with the 5E model (Artun & Costu, 2013). The 5E model is a constructivist approach to science teaching that uses inquiry to break down student misconceptions and teach desired conceptions of science concepts. It has been shown to be an effective method of developing conceptual knowledge.

Many studies have been conducted on conceptual change in science education (Artun & Costu, 2013). Conceptual change refers to alterations in knowledge and understanding of topics over a period of learning. These studies have covered a wide variety of topics; however, research on diffusion and osmosis is limited. Because of this, Artun and Costu investigated the effects of the 5E model on primary teachers’ conceptions of diffusion and osmosis. In particular, the investigation studied whether conceptual change resulted from the implementation of the 5E model, how much conceptual change occurs, and whether they were long-term changes.

In order to answer the questions, a sample of prospective primary teachers was taken (Artun & Costu, 2013). There was a total of 50 participants with 28 being male and 22 female. The ages ranged from 18 to 23 years and while the participants came from different cities in Turkey, they all attended the same university. The prospective teachers were taught the concepts of diffusion and osmosis using a 5E model approach. The lessons incorporated each phase of the 5E model and took between 70 and 100 minutes to implement.
Participants completed a pre- and post-test for researchers to determine preconceptions and difficulties of diffusion and osmosis (Artun & Costu, 2013). This test was known as a Diffusion and Osmosis Concept Test, which used multiple choice and short-response questions. The questions were two-tiered, meaning the participant not only chose an answer, but also justified it. Interviews were also conducted to develop a deeper understanding of participant learning.

According to Artun and Costu (2013) analysis of the data showed that participants’ alternative conceptions and difficulties changed over time. The most conceptual change was exhibited by above average participants while the least conceptual change was exhibited by below average students. A significant difference was noticed between performances on the pre-test and the post-test; however, no significant difference was noticed between the post-test and the delayed post-test.

A limitation of the study is its focus on undergraduate level students. Students in college level courses will have had more experience with science learning and life as compared to a high school student. This may suggest an openness to new ideas and changing their own conceptions. It does provide insight to how effective the 5E model can be as a teaching tool. The sample population also was only taken from a single university. Widening the population from which participants originated may provide more insight to a generalization about conceptual changes.

Artun and Costu (2013) developed conclusions that were consistent with other studies on specific topics in science. It was determined that students’ alternative conceptions and conceptual change can arise from the implementation of the 5E model. Because the pre- and post-test scores were significantly different, it could be argued that the 5E model is an effective teaching approach to science. This provides evidence for its validity in the science classroom.
Furthermore, the pre-service teachers in the study were able to improve their understanding of diffusion and osmosis. The 5E model promoted self-reflection on beliefs and the phases in the model helped to develop a more suitable conception about science. Some teachers did not alter their conceptions at all. This could have been due to prior knowledge being consistent with desired conceptions or students being firm in their beliefs on the topic.

This study has implications for a high school classroom in that many students will enter the class with preconceptions about the topic being investigated. Determining the best method for addressing these preconceptions can be a daunting task. Implementation of the 5E model is supported by previous research to increase conceptual understanding and address misconceptions. Through the 5E model, students are also building critical thinking and metacognitive skills.

Science education reform is said to be pushing for inquiry-based learning that focuses on students investigating phenomena in a similar fashion to real-world scientists. One model that has gained popularity to align with this push is the 5E model developed by Roger Bybee (Sickel & Friedrichsen, 2015). This approach engages students in a topic whilst exhibiting their prior knowledge, followed by an exploration of a phenomenon related to the topic. Students would then explain the phenomenon, apply the new knowledge to other contexts and ultimately get evaluated on the topic.

While use of the 5E model is supported by research, there is little evidence suggesting that teachers continue to implement it consistently. As such, Sickel and Friedrichsen (2015) set out to understand how a beginning teacher implements the 5E model and modifies their practices over the course of a few years. The investigation questions focused on a single teacher and were
related to her beliefs about teaching and learning, developed practical knowledge of the 5E process, and how context influences perceptions of the 5E model.

Investigation of the questions involved a case study that spanned a three-year period (Sickel & Friedrichsen, 2015). The focus of the case study was a biology teacher who designed and implemented a 5E unit on natural selection. The focus teacher, who began as a first-year teacher, changed school districts after year one and, in the process, made modifications to the unit. The classes in which the participant taught were 10th grade biology classes and an applied biology course in two different large high schools. In the second school district, the teacher was expected to plan and work as a team on assessments and objectives with the other biology teachers in the district. Sickel and Friedrichsen specifically studied the teacher’s thoughts about science teaching and learning, relevant knowledge, and school context as it relates to the 5E model.

Data collection was completed using interviews, video-recorded observations, and lesson materials (Sickel & Friedrichsen, 2015). Coding was used to analyze the transcribed interview data and observations. This was done through multiple methods in order to extract pertinent data about beliefs, knowledge of 5E model implementation, and perceptions, which were developed into four assertions. It was found that the implementation of the 5E model in year one utilized all of the phases. In years two and three, on the other hand, a focus was placed on the Explore phase, Explain was not as emphasized, and Elaborate was eliminated. The teacher believed that students learn by observing and interacting with phenomena to discover concepts while the teacher facilitates. Students, the teacher claimed, enjoyed visual representations but had difficulty understanding natural selection and applying it to new concepts. The teacher also
discerned the need to plan and work with other team members as a hindrance on the 5E model unit.

A limitation of the study is its focus on a single teacher who transferred school districts after one year. The participant was a beginner teacher that was still in the process of developing her curriculum before she transferred and was required to abide by specific rules. Keeping that in mind, variation in the perceptions of context may have been seen should the teacher have stayed in the same district she started in for a few more years. Also, investigating more than one individual, especially in more than one discipline would be beneficial for gathering more information about beliefs of the 5E model, consistent implementation and perceptions.

Sickel and Friedrichsen (2015) determined that personal beliefs about teaching practices and the 5E model play a significant role in its implementation. The participant in the study faced a few challenges that deterred her from utilizing the 5E model, and while she did alter its implementation slightly, she continued to use it throughout her teaching. This is evidence of the participant’s strong belief in the effectiveness of parts the 5E model and neglect of others. Thus, beliefs can play both a negative and positive role in the implementation of the 5E process. One phase that was left out was the Elaborate phase, suggesting that the participant, and potentially other beginning teachers, do not have a strong belief or background in utilizing it. This could be interpreted as a need for science teacher education programs to focus on inquiry learning and applying knowledge to new contexts.

It can also be concluded that the 5E model is an effective approach to teaching science. Implementing it can be a challenge depending on district requirements; however, portions of it can still be beneficial for student learning. Depending on the knowledge level of the students and other factors, modifications may be necessary to most effectively teach using the 5E process.
Traditional classrooms take on a lecture-based approach where the teacher is the center of the learning and students are meant to simply listen. Come assessment time, the expectation is that the students can regurgitate the information they listened to during lectures. This is especially the case in large college classrooms that reside in lecture halls consisting of upwards of 300 students. Sickel, Witzig, Vanmali, and Abell (2013) make the claim that this form of teaching frustrates students and ultimately leads to their disinterest in the subject.

Educational reform at all levels is urging teachers to implement more student-centered approaches. A student-centered approach involves more inquiry-based learning and collaboration between the students. This collaboration leads to much discussion where students could learn from each other. One way in which this can be done is through the implementation of the 5E model (Sickel et al., 2013). Discourse is an important aspect of the 5E model and Sickel et al. sought to understand its role as part of the model. Thus, they set out to investigate the nature of discourse in a large enrollment college biology course.

In order to investigate their question, Sickel et al. (2013) studied a biology class at a large Midwestern United States University. The course consisted of 377 students and was taught by a member of the research team. Participants were of varying ethnicity, gender, age, and major. The study took place over the course of four lessons that were developed based on the 5E model. Topics covered in the lessons include macro and micro evolution, human variation, population genetics of sickle cell anemia and malaria, and regulation of cell division. These topics were chosen because they were easily modified into a 5E lesson plan and students had become accustomed to regular discussion.

Data collection was completed using video- and audio-recorded whole-class and small-group discussions (Sickel et al., 2013). The recordings were transcribed and then separated based
on the phase of the lesson (Engage, Explore, Explain, Elaborate, and Evaluate). Coding was then used to analyze the data. The focus was on determining purpose, content, communicative approach, patterns, and interventions in the data.

Sickel et al. (2013) found that the nature of discourse varied throughout the phases of instruction. Thus, each phase had its own set of purpose, patterns, etc. The second lesson (human variation) was also significantly different than the other lessons, leading to the belief that the topic also influenced discourse. Engage had minimal discourse as the instructor played an important role through talking without warranting much response. Explore and Elaborate utilized small group discussions while Explain had a more whole-class approach. Like Engage, Evaluate strayed away from discourse with the only difference being that students were the main speakers (after a question was asked).

A limitation of this study is its focus on a large enrollment classroom at a university. While this does provide insight into the nature of discourse with the 5E model, this may be specific to such a class. In contrast, a small high school classroom would have a different student dynamic and the nature of discourse could exhibit different outcomes. Further research could investigate the nature of discourse in an elementary, middle, or high school classroom. This would allow generalization to be made for different age groups. It would also be possible to then make comparisons between different levels of science.

Sickel et al. (2013) concluded that the focus of each phase of the 5E model is what drives the discourse in the lesson. For example, the Explore phase involves investigating a phenomenon and developing a model to then explain it. During this situation, a teacher would ask questions that could be supported by multiple explanations and would drive a dialogue between students in small groups. It was also determined that the discourse taking place has the ability for students to
internalize information and develop meanings for the material. Furthermore, socioscientific issues can be used to drive discourse because of their real-world relevance and ability to draw multiple viewpoints.

The 5E model provides teachers with support to engage students in discussion through meaningful ways. It is meant to be completed in a sequence that outlines purpose and drives learning through inquiry-based instruction. With the 5E model, students have the ability to weave their prior learning into new concepts and develop explanations to questions they may never have thought they could answer.

**Three-Dimensional Learning**

It could be argued that for students to become scientifically literate citizens, they must develop specific science-based skills throughout their time in school (Gotwals & Songer, 2013). Such skills involve the use of science and engineering practices, which are one of the three dimensions of learning presented by the Next Generation Science Standards. The other two dimensions, crosscutting concepts and disciplinary core ideas, work in conjunction with science and engineering practices to foster student learning. These dimensions stray away from rote memorization and instead, promote engagement, critical thinking, and argumentation, among other skills.

The NGSS have placed an emphasis on learning progressions and linking disciplinary core ideas to scientific practices in the classroom (Gotwals & Songer, 2013). The Framework, which was developed by the National Research Council is what outlines these promotions and provides examples of practices linked with ideas. This takes place in the form of performance expectations, which are meant to be assessed for evidence of learning. Taking the Framework and standards a step further would mean developing assessments for the performance
expectations. Gotwals and Songer sought to do exactly this and evaluate the tasks that were created to assess the combination of disciplinary core ideas with science and engineering practices.

In order to develop assessments for three-dimensional learning, Gotwals and Songer (2013) first created learning progressions for an upper-elementary science course that focused on ecology. They then designed assessments that would demonstrate student learning to three different levels based on ability; the lowest level contained the most scaffolding, while the highest level contained no scaffolding. In developing learning progressions and assessments in conjunction with each other, the researchers were able to determine more information about learning for a larger range of students.

Collecting data to demonstrate the validity of their assessments for the learning progressions was done in Detroit Public Schools, which houses about 183,000 students in 263 schools (Gotwals & Songer, 2013). This is an urban school district in which 94% of students identify with ethnic backgrounds and over 70% of students qualify for free and reduced lunches. The developed ecology program was implemented specifically in three of the schools with three different teachers at the sixth-grade level. Overall, over 300 students participated in written assessments and 20 students participated in think-alouds and interviews. The written assessment was based on 20 questions that covered ecological ideas and scientific explanations.

A focus of the analysis was to assess student abilities to combine ecological ideas with evidence-based explanations (Gotwals & Songer, 2013). Analysis of the data was done through coding. It was determined that the assessments provided students with the ability to demonstrate their knowledge of disciplinary core ideas while supporting their claims with evidence. Reasoning was found to be the most difficult aspect of creating evidence-based explanations.
with lower level students rarely demonstrating this skill. In contrast, making a claim was the easiest part of doing so.

A limitation of the study is its focus on an upper-elementary ecology class. Students in elementary school are not expected to have the same level of understanding or skill set that a high school student would. With that in mind, the assessments would have to be different in order to accommodate for a student of that age as it pertains to explanation and reasoning requirements. The ideas behind assessment development would be similar; modifications for the level of difficulties would be necessary.

Gotwals and Songer (2013) were able to conclude that the use of learning progression-based assessments can pose difficulties and do require scaffolding to elicit answers. Including scaffolding in the assessments was beneficial for low-level and middle-level students in being able to provide evidence for claims. For demonstration of reasoning, on the other hand, the scaffolding provided no assistance for the students. In order to combat this, it was determined that adding prompts a teacher might use in class could be useful.

Further implications of this study suggest a means for assessing students that align with the three-dimensions of the NGSS. Asking students to develop claims based on evidence and reasoning skills was shown to be a useful method of assessment of student learning of disciplinary core ideas. In doing so, students are utilizing science and engineering practices in conjunction with disciplinary core ideas.

The recent introduction of the Next Generation Science Standards has led to the implementation of three-dimensional learning. Three-dimensional learning refers to science education that incorporates disciplinary core ideas, crosscutting concepts, and science and
engineering practices. It is claimed that by engaging students in three-dimensional learning, they will be able to make more connections between various science concepts and as a result, build problem solving skills and the ability to make sense of new information (Plummer & Small, 2018).

One method that has the potential to increase three-dimensional learning engagement is with museums and planetariums (Plummer & Small, 2018). Despite this theory, there is minimal research supporting that such field trips do promote three-dimensional learning. Prior research on field trips has focused on content learning and perceptions of science rather. As such, Plummer and Small sought to investigate how a planetarium field trip might support science learning.

Conducting the study specifically involved a planetarium field trip and two classroom lessons that integrated the three dimensions of the NGSS (Plummer & Small, 2018). The lessons focused on lunar phenomena and were developed for a first-grade classroom. For the learning segment, the disciplinary core idea was “the Earth and the Solar System,” the crosscutting concept was “patterns,” and the practice was “modelling” (p. 194). The major question of the study revolved around how students’ three-dimensional learning changed from before to after the planetarium trip and classroom lessons.

Data collection for the study took place using qualitative and quantitative methods (Plummer & Small, 2018). This involved the use of interviews, audio recorded planetarium visit, and video recorded lessons. The interviews were conducted one week prior to and after instruction and then again, one year later. Participants in the study came from four different first-grade classrooms for a total of 46 students. These classrooms were from a suburban elementary school in the Northeastern United States.
Data analysis involved the use of coding and statistical analysis that revolved around the ideas of the daily motion of the moon and its monthly cycles (Plummer & Small, 2018). It was found that initially, students did not believe that the moon appeared to move. After intervention, this perception was changed. This was indicated in their explanations and drawing representations. Similar improvements were noticed as it pertains to the moon’s monthly cycles based on explanations and representations. The delayed interview showed that students retained this knowledge for the most part.

A limitation of this study is the fact that it was conducted using first-grade classrooms. This is a limitation because it doesn’t provide direct assumptions for the high school level and a field trip’s influence on three-dimensional learning. Another limitation is in the difficulty to distinguish between the effects of the planetarium trip versus those of the classroom lessons. Further research could utilize a control group to compare between a field trip and classroom lesson. It could also be conducted at different levels of science to determine influences at those levels.

Plummer and Small (2018) concluded that improvements were made in three-dimensional learning as students were engaged in a planetarium visit coupled with classroom lessons. The planetarium was a useful resource in developed conceptual learning and patterns in lunar phenomena. Instruction included kinesthetic movements, and visual and verbal cues. Furthermore, the progress that was made during the learning segment allowed students to build science connections that could be useful in the future of astronomy learning.

The benefit of field trips with a science concept focus is that it can help students to develop observational skills as it pertains to phenomena. In doing so, analysis skills can be utilized and then construction of explanations can be fostered through discussion. Incorporation
of patterns or other crosscutting themes would then round out the implementation of three-dimensional learning.

Because of the push for real-world science it would be beneficial to occasionally incorporate field trips in the classroom. This can help students to see how real life pertains to what is being learned in the classroom. It may also help students to recognize the importance of the three-dimensions of learning in the NGSS. A planetarium was shown to be engaging for young children and taking high school students on a trip in which they perform a real-world investigation may yield similar engagement. The other benefit is that such a trip would align with the NGSS.

Prior to the introduction of the Next Generation Science Standards, science education focused on teaching conceptual knowledge and scientific practices separately (Wyner & Doherty, 2017). The downside to this approach is the disconnect that students may experience between the two constructs. Occasionally, students may fail to recognize the importance of one in learning the other and vice versa and how they pertain to real science. With the introduction of the NGSS, a new approach called for the teaching of knowledge and scientific practices together, as well as crosscutting concepts. This new approach is known as “three-dimensional learning” (p. 787).

In order to determine how the three dimensions can come together to increase learning, learning progressions can be used. Learning progressions can provide researchers and curriculum developers information in a coherent manner through learning outcomes and assessments. Wyner and Doherty (2017) decided to use a learning progression for the topic of evolution to better understand the intertwining of crosscutting concepts, disciplinary core ideas, and science and
engineering practices. They specifically wanted to discover how students made progress towards three-dimensional learning of evolution through this method.

After the development of the learning progression on evolution, it was implemented in the classrooms of various teachers (Wyner & Doherty, 2017). There were 12 participating teachers who taught middle school classes in 6 different Eastern United States city schools. Prior to teaching the curriculum, which focused on street tree evolution, the teachers participated in professional development concerning the material.

A total of 308 students across sixth through eighth grade participated in the study (Wyner & Doherty, 2017). Of the six participating schools, four of them contained many students eligible for free or reduced lunches. These same schools were also primarily comprised of African American and Latino students. The other two schools were predominantly white and Asian and had a minimal number of students eligible for free or reduced lunches. Half of the schools also had a significant English Language Learner population.

In order to collect data, Wyner and Doherty (2017) conducted student interviews and had the students complete written assessments. Students were assessed four times: prior to and after fall implementation of the learning progression and prior to and after spring implementation. Analysis was conducted using coding and comparative methods. Students exhibited four levels of knowledge based on ability to group trees with higher reasoning. They also showed three levels of understanding of the definition of being related. The interview responses and written responses were similar in terms of demonstrated ability; however, the interview responses were more descriptive. Overall, students showed growth over the course of curriculum implementation. The growth was shown to be in breaking down misconceptions and increasing understanding of common ancestry and relatedness.
A limitation of the study is based on the used population for participation. The focus students all came from six middle schools in a city school. In order to improve the findings from this study, it would be beneficial to have incorporated students from rural and suburban school districts. Furthermore, a larger population size could have provided more insight to the research that was conducted.

Wyner and Doherty (2017) were able to conclude that the implementation of scientific practices and patterns (a crosscutting concept) in teaching were able to help students better identify and group living organisms. This helped to build observational and hypothesis-developing skills. A task completed during the learning progression was categorization of organisms based on the structures that made them up. This helped students to place learning in the context of a specific disciplinary core idea, which in this case was evolutionary relatedness. This outlines the importance of students understanding what they are doing and why they are doing it. In doing so, they are better able to have an accomplishment in mind, especially as they aim to emulate real science.

Wyner and Doherty (2017) successfully developed a learning progression that utilized three-dimensional instruction and implemented it in classroom settings. This learning progression was found to increase student understanding of evolution concepts, which demonstrates the importance of utilizing the three dimensions. This study provides support for using ideas set forth by the NGSS. Moving forward, research could be conducted on learning progressions and curriculum that implement three-dimensional learning for various concepts and disciplines. For instructors, this means constructing such curriculum to instruct students more efficiently.
Science and Engineering Practices

Berland, Steingut, and Ko (2014) contend that national educational policies have recently pushed for the integration of engineering in K-12 science classrooms. The purpose behind this is because of the ability of engineering practices to provide science concepts with real-world application and introduce students to engineering at a young age. Engineering is also said to be an important discipline of education and increase student learning in the science classroom. Minimal research has been conducted to support such claims.

Including engineering is found to be challenging to implement in science classrooms; however, the incorporation of one method has been thought to overcome the challenges and that is the design process (Berland et al., 2014). The design process is one of the core ideas found in the new framework of the Next Generation Science Standards and it is a central aspect of engineering, thus aligning the classroom to the work of engineers. It often involves defining a problem, finding multiple solutions, modeling and analyzing, and repetition of the process. Berland et al. (2014) conducted a study to determine the effects of the utilization of engineering design on science and math learning. Specifically, they investigated student understanding of the major characteristics of engineering design and their perceptions on how those characteristics provide opportunities to learn science and math.

In order to conduct the study, Berland et al. (2014) collected data from a high school engineering course that takes place over the course of a year. The course taught students six engineering units, each of which focused on a specific design problem. This specific course was taught in multiple Texas high schools, seven of which were used for data collection. A few of the schools were considered urban and the remainder were considered suburban. There were 179 students who participated in the study, with the majority being seniors who had taken or were
taking a physics course. The rest of the students were sophomores and juniors. Of the participants, the majority were white males who had parents with at least two years of formal education.

Data collection was completed using questionnaires and interviews (Berland et al., 2014). The questionnaire assessed student understanding of the engineering design process. Interviews, on the other hand, were only conducted with 16 of the participants and were used to develop a better understanding of questionnaire responses. Both data collection tools were coded in order to perform an analysis, which was focused around the four major steps of the design process: defining a problem, developing multiple solutions, modeling and analyzing, and iteration.

Based on analysis of the data, Berland et al. (2014) found that students are more comfortable and knowledgeable of the qualitative aspects of engineering design rather than quantitative aspects. Questionnaire data showed that students were familiar with and understood the importance of identifying the problem, developing multiple solutions, and iteration, along with underlying themes. The interviews support these claims. Modeling and analyzing was not explored due to limitations of the curriculum, however.

A limitation of this study is its focus on an engineering classroom. For purposes of investigating the benefits of engineering practices in a science curriculum, it may be beneficial to implement the design process in a science course. This places the focus on science concepts and uses engineering as a vehicle rather than focusing solely on the engineering aspect. In doing so, researchers could develop strategies for integration of engineering in science classrooms. Another limitation can be found in the data collection tools. Students were not explicitly asked about their perceptions of engineering on science and math learning. Instead, this was inferred based on analysis. Future studies could investigate using both ideas.
Berland et al. (2014) concluded that the aspects of the engineering design process that were most conducive to math and science learning were the quantitative aspects, such as developing mathematical models and systematic approaches to selecting solutions. Students were not deemed to have valued these parts of the design process, suggesting that they struggle with this aspect of learning. This struggle is likely the reason behind teachers’ need to overcome challenges in engineering implementation. Despite this, Berland et al. did not find evidence contradicting the claim that engineering implementation supports a positive learning environment.

The challenge that science educators must overcome is developing a strategy that engages students in the quantitative aspects of engineering. One suggested way to do this is to utilize science concepts that benefit from engineering design and are useful for real-world knowledge (Berland et al., 2014). Furthermore, use of the qualitative aspects of engineering, such as identifying needs and developing solutions, can help to increase motivation and interest to engage in science and math.

It could be argued that many teachers still educate science students using a teacher-centered approach even though reform has pushed for using a student-centered approach. With the acceptance of the Next Generation Science Standards, there is a greater push for student-centered learning, especially with integration of engineering practices and core ideas (Boesdorfer, 2017). This change, however, has been met with some resistance for various reasons. Some of them are because of the teachers themselves, while others are because of requirements of the schools they teach at.

Many teachers often feel unprepared to teach engineering practices or student-centered approaches (Boesdorfer, 2017). Some also do not feel the need because they were taught through
teacher-centered approaches and had success. Reducing this resistance has been shown to be possible using professional development training. It is also possible to encourage younger teachers through their education programs and further professional development as they begin teaching. The impacts of such professional development were investigated by Boesdorfer. The question investigated focused on changes to teaching methods reported by chemistry teachers who participated in professional development for engineering.

The study conducted by Boesdorfer (2017) was centered around 24 high school chemistry teachers with a range of experience spanning 20 years. The teacher with the least number of years teaching had only 2, the greatest number was 22 years, and the average was 11 years. Most of the teachers (16) taught in rural school districts while the remaining 8 taught in suburban or urban school districts. Many taught more science courses other than chemistry and of the participants, 18 were females and 6 were males.

The teachers participated in a professional development course with the goal of increasing their understanding of engineering design and how it could be utilized in a chemistry curriculum (Boesdorfer, 2017). One benefit of the professional development was to learn engineering activities aligned with the NGSS that were developed by teachers. The structure of the course was to have teachers participate in the activities as students and then engage in discussion about them afterwards.

Prior to the professional development, the participants completed a survey about engineering and teaching methods (Boesdorfer, 2017). The same survey was completed afterwards, along with questions about the professional development. Also collected, were class notes, handouts, activities, and conversation notes. A follow-up survey was conducted a year
later on 23 of the participants. The 24th participant was observed interviewed and took surveys as part of a case study.

Upon initial analysis of the data, Boesdorfer (2017) found that teachers did express an increase in the use of student-centered approaches to teaching. The open-ended survey questions also showed a change or adaptation to the participants’ teaching methods. Other responses included adding supplemental practices to methods of teaching through the use of engineering activities. Analysis of the case study showed that implementation of engineering activities helped to reduce the challenges of inquiry and students responded positively to the learning experiences.

A limitation of this study is its sample size. Only 24 teachers participated in the study and 1 of them was studied extensively as part of a case study. While the teachers came from various backgrounds, the limited number of participants reduces the reliability of generalizations being made. The surveys utilized may not have provided accurate representations of the teachers’ thoughts or practices. Further research could include a larger sample population and more case studies, or an increased number of effective data collection tools.

Boesdorfer (2017) concluded that the study conducted provided evidence for successful implementation of engineering practices in a science classroom. Doing so required modifications to teaching methods from the standpoint of activities and engineering utilization rather than science. This implies that making learning student-centered and inquiry-based requires changing practices from a methodology standpoint rather than a conceptual standpoint. With proper training and understanding it is possible to incorporate engineering practices into the classroom, thus aligning learning with the NGSS.
This study provides evidence for including engineering practices in the classroom as a means for enhancing student learning. From the teacher’s perspective, it takes practice and may be daunting at first, but it can be done. Students expressed increased interest in not only science, but also the inquiry aspect of learning. Further research could be conducted to explicitly study the effects of engineering implementation on student learning of science and their perceptions.

**Assessment/Scaffolding**

An important aspect of education is the assessment of student learning. While there are various types of assessments, the main goal is to determine what students know and support learning (Kang, Thompson, & Windschitl, 2014). These are designed by the teacher and provide information about student understanding, gaps in knowledge, and reasoning processes. The teacher will use assessments throughout a unit to adapt teaching methods. Depending on the assessment and knowledge desired, scaffolding may be necessary to unlock students’ full potential.

Minimal research has been conducted on the types of scaffolding used within assessments and how it can support learning (Kang et al., 2014). There has, however, been research on design of assessments themselves, though it has mostly been conducted on outside rather than teacher-produced assessments. That said, assessments can provide an opportunity for students to grow through construction of their perceptions and understanding of material. There is a lack of generalizations on what forms of scaffolding help to optimize student growth and achievement. Kang et al. sought to investigate exactly which scaffolding techniques teachers use in devising assessments and how they relate to the quality of students’ scientific explanations. Furthermore, they wanted to determine if there was variation in the quality of explanations based on quality and combinations of scaffolding.
Conducting the study involved a mixed-methods approach (Kang et al., 2014). Overall, 33 teachers participated in the study, each of which were first-year teachers who graduated from a teacher education program from a United States public university and taught secondary science. Their assessment tasks (written evidence-based tasks) and samples of student work were collected. A total of 707 student work samples were used along with 76 assessment tasks. The student work samples exhibited a range of abilities from exceptional learners to learners with disabilities, English Language Learners, and everything in between.

According to Kang et al. (2014), data was analyzed using coding and regression analysis. Teachers were found to use five different types of scaffolding: allowing drawings in combination with writing, contextualization with a phenomenon or event, checklists, rubrics, and sentence frames. One type of scaffolding was used most often while the use of two or three types immediately followed. Scaffolding was shown to be significantly associated with the quality of student explanations with phenomenon having the greatest association and sentence frames having the least. As for combinations of scaffolding, the most significant combination was one that included three or more upper level (more sophisticated) scaffold types.

A limitation of this study is that the focal point is on written explanation assessments. With a variation of assessment types, utilization of a greater range could allow for accurate generalizations of scaffolding across assessments. Further research could be conducted with different assessment tasks. It could also consider assessments at different points in a unit or learning segment (formative assessment versus summative assessment).

Kang et al. (2014) were able to conclude that effective use of scaffolds can provide better opportunities for students to illustrate their knowledge of the material being covered. Contextualization of phenomena is one such scaffolding technique that can yield positive results.
in terms of student explanation quality. It is also noted that the quality and combination of scaffolding types plays more of a role than sheer number of scaffolding techniques. This is important to consider when constructing assessment tasks and determining how best to draw out student responses. Without scaffolding, some students, especially those at lower ability levels, may be unable to access the knowledge necessary to provide adequate answers.

Students are consistently assessed every day that they come into the classroom. With the Next Generation Science Standards and the push towards a student-centered classroom, developing adequate assessments is imperative. Not only can it provide the teacher with information about student understanding, but it can also provide students with some direction as they participate in the inquiry process. The study conducted by Kang et al. (2014) provides examples of scaffolding techniques that are commonly used by teachers and how they influence student responses. It also provides evidence to support the use of phenomena as mentioned in the Framework document for the NGSS. Moving forward, development of assessments could implement the scaffolding examples in various combinations depending on the task and desired outcome.
Chapter 3: Learning Segment and Rationale

Throughout this learning segment, students will be engaging in three-dimensional learning, which has been shown to improve student understanding of concepts (Fick, 2017). Each instruction throughout these 5E phases have been carefully constructed to incorporate each dimension. In order to show outline this fact, the plans in the Engage phase (and every phase hereafter) have been color coded. Blue represents the Science and Engineering Practices, while green represents the Crosscutting Concepts, and Orange represents the Disciplinary Core Ideas.

Alignment to the three dimensions of the NGSS has been done using a 5E Model Approach with the Gather, Reason, Communicate Sequence embedded within. The purpose is to foster student learning in a way that increase inquiry learning and argumentation in science. Both ideas have been found to improve student understanding of science (Artun & Costu, 2013; Cavagnetto & Kurtz, 2016).

The following learning segment is meant to be used by a teacher. Students are provided prompts that can be found at the end. This way, the teacher can supplement the students as necessary and students have an idea of the expectations throughout the segment.


| Student Science Performance |
| Author(s): Corey Hollister |

<table>
<thead>
<tr>
<th>Grade Level- 10-12</th>
<th>Topic - Reaction Rates</th>
</tr>
</thead>
<tbody>
<tr>
<td>NYSSLS Performance Expectation(s):</td>
<td></td>
</tr>
<tr>
<td>HS-PS1-5. Apply scientific principles and evidence to explain how the rate of a physical or chemical change is affected when conditions are varied.</td>
<td></td>
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<tr>
<td>Clarification Statement: Explanations should be based on three variables in collision theory: number of collisions per unit time, particle orientation on collision, and energy required to produce the change.</td>
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</tbody>
</table>
Conditions that affect these three variables include temperature, pressure, nature of reactants, concentrations of reactants, mixing, particle size, surface area, and addition of a catalyst. [Assessment Boundary: Assessment is limited to simple reactions in which there are only two reactants and to specifying the change in only one condition at a time.]

Lesson Performance Expectations Specific to this Lesson/Unit:

- I can explain how the addition of specific substances (a catalyst) can alter the rate of a reaction.
- I can explain how changing temperature can alter the rate of a reaction.
- I can explain how the concentration of reactants and surface area can alter the rate of a reaction.
- I can explain how a catalyst changes the reaction mechanism of a reaction.
- I can argue how changing pressure or mixing reactants can alter the rate of a reaction.
- I can utilize the ideas behind collision theory to combine reactants to create a more useful product.
- I can construct an argument about how collision theory can account for real-world phenomena.

The science and engineering practices, disciplinary core ideas, and crosscutting concepts immediately following were selected based on their use within this 5E/GRC Sequence Unit. The NGSS do not directly correlate some of these practices or concepts with the disciplinary core ideas investigated; however, after construction of the unit, it was decided that they were necessary to build student understanding and so have been included in this outline.

<table>
<thead>
<tr>
<th>Science and Engineering Practices</th>
<th>Disciplinary Core Ideas</th>
<th>Crosscutting Concepts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constructing Explanations and Designing Solutions</td>
<td>PS1.B: Chemical Reactions</td>
<td>Patterns</td>
</tr>
<tr>
<td>- Apply scientific principles and evidence to provide an explanation of phenomena and solve design problems, considering possible unanticipated effects.</td>
<td>- (NYSED) Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collisions of particles and the rearrangements of particles into new substances, with consequent changes in the sum of all bond energies in the set of substances that are matched by changes in energy.</td>
<td>- Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.</td>
</tr>
<tr>
<td>Developing and Using Models</td>
<td>Chemistry Core Curriculum</td>
<td>Cause and Effect</td>
</tr>
<tr>
<td>- Develop a model based on evidence to illustrate the relationships between systems or between components of a system.</td>
<td>- 3.2a A physical change results in the rearrangement of existing particles in a substance. A chemical change results in the</td>
<td>- Relationships can be classified as causal or correlational, and correlation does not necessarily imply causation.</td>
</tr>
<tr>
<td>Analyzing and Interpreting Data</td>
<td></td>
<td>Stability and Change</td>
</tr>
<tr>
<td>- Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in</td>
<td>Chemistry Core Curriculum</td>
<td>- Much of science deals with</td>
</tr>
</tbody>
</table>
order to make valid and reliable scientific claims or determine an optimal design solution.

**Planning and Carrying Out Investigations**

- Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly.
- Select appropriate tools to collect, record, analyze, and evaluate data.

**Engaging in Argument from Evidence**

- Evaluate the claims, evidence, and reasoning behind currently accepted explanations or solutions to determine the merits of arguments.

**Asking Questions and Defining Problems**

- Analyze complex real-world problems by specifying criteria and constraints for successful solutions.

**Obtaining, Evaluating, and Communicating Information**

- Evaluate the validity and reliability of multiple claims that appear in scientific and technical texts or media reports, verifying the data when possible.
- Communicate technical information or ideas (e.g. about phenomena and/or the process of development and the design and performance of a proposed process or system) in multiple format (including orally, graphically, textually, and mathematically).

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formation of different substances with changed properties.

- **3.4d** Collision theory states that a reaction is most likely to occur if reactant particles collide with the proper energy and orientation.
- **3.4f** The rate of a chemical reaction depends on several factors: temperature, concentration, nature of the reactants, surface area, and the presence of a catalyst.
- **3.4g** A catalyst provides an alternate reaction pathway, which has a lower activation energy than an uncatalyzed reaction.
- **3.4h** Some chemical and physical changes can reach equilibrium.
- **3.4i** At equilibrium the rate of the forward reaction equals the rate of the reverse reaction. The measurable quantities of reactants and products remain constant at equilibrium.

constructing explanations of how things change and how they remain stable.
## Materials Required:

<table>
<thead>
<tr>
<th>Engage</th>
<th>Explore 1</th>
<th>Explore 2</th>
<th>Explore 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Hydrogen Peroxide 3% (H₂O₂)</td>
<td>• Glow Sticks</td>
<td>• Hydrochloric Acid 1M (HCl)</td>
<td>• Plastic Cup</td>
</tr>
<tr>
<td>• Manganese Dioxide (MnO₂)</td>
<td>• Alka Seltzer Tablets</td>
<td>• Hydrochloric Acid 0.1M (HCl)</td>
<td>• Saturated Copper II Sulfate (CuSO₄)</td>
</tr>
<tr>
<td>• Hydrogen Peroxide 30% (H₂O₂)</td>
<td>• Tap Water</td>
<td>• Mossy Zinc</td>
<td>• Salt</td>
</tr>
<tr>
<td>• Sodium Iodide 2M (NaI)</td>
<td>• Ice</td>
<td>• Hammer</td>
<td>• Aluminum Foil</td>
</tr>
<tr>
<td>• Dish Soap</td>
<td>• Hot Plate</td>
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<tr>
<td>• Food Coloring</td>
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<tr>
<td>• Graduated Cylinder</td>
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<table>
<thead>
<tr>
<th>Explain</th>
<th>Elaborate</th>
<th>Evaluate</th>
</tr>
</thead>
<tbody>
<tr>
<td>• None</td>
<td>• Line-X Video</td>
<td>• Hindenburg Video</td>
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<td>(Veritasium – Indestructible</td>
<td>(Hindenburg Disaster: Real Zeppelin</td>
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<td>Coating!?)</td>
<td>Explosion Footage</td>
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</table>
### Engage Learners

The Engage phase has the purpose of capturing students’ attention and interest, while focusing on a phenomenon and ideas of the phenomenon that are related to a standard. Students have the task of making sense of the chosen phenomenon using their own conceptions.

During this phase, students develop initial explanations of the phenomenon. Doing so provides the teacher with the opportunity to see preconceptions.

**Teacher Actions:**
The teacher’s role is to develop opportunities to determine student misconceptions.

### Student Science Performances

**Phenomenon:** Hydrogen peroxide reacts differently under varying conditions to produce different amounts of oxygen.

**Gather:**

1. Students **carry out an investigation to obtain evidence** for causes of differences in the **rate of reaction** through the **addition of a catalyst**.
   a. Students pour a small sample of 3% hydrogen peroxide into a test tube and record observations.
   b. Students are provided with a small sample of an unknown substance (MnO$_2$) and pour it into the test tube containing hydrogen peroxide. Students continue to make observations, commenting on changes.

2. Students **ask questions about patterns in present in the chemical reaction rates** of different reactions.
   a. The class is shown the “Elephant Toothpaste Demo” and students make observations.

**Teaching Suggestions:**

- Questions to consider:
  - What changes are occurring as the hydrogen peroxide sits in the test tube?
  - How did the addition of a new substance change the hydrogen peroxide?
  - What changes were noted in the Elephant Toothpaste demonstration?
  - What kind of changes were these?

**Reason:**

3. Students **compare and contrast patterns** presented in the three chemical reactions observed.

4. Students **develop an explanation for causes of the differences in reaction rates**.

**Teaching Suggestions:**

- Students should be led to the idea that some substance (a catalyst) causes a change in chemical reactions (increases the reaction rate).
- Students have previously been exposed to catalysts in Living Environment. Draw on this to ask questions and lead them towards the idea that a catalyst increases the reaction rate.

### Class Discussion

- What changes were noticed in each observation?
- What patterns are noticed in each of the reactions observed? (compare/contrast)
- How did the addition of a substance change the reactions?
- What was the substance that was added to the reactants?
- Have you seen something like this in a previous class? If so, what was it and what did it do?
Communicate:

5. Students argue about patterns in chemical reactions and how they can be manipulated to investigate factors that influence reaction rates.

Teaching Suggestions:

- Students should be led to think about temperature, energy, concentration, particle size, etc.
- Questions to consider:
  - What is required for a reaction to occur?
  - Do all chemicals that come in contact react? Why or why not?
  - What factors could be changed?
  - How could those factors be manipulated?
  - What changes might occur as a result of those manipulations?

Engage Rationale:

According to Moulding and Bybee (2017), the Engage Phase is meant to garner interest from students and provoke thought about science phenomena. Because this unit is based on chemical reactions and collision theory, it was decided that the Engage phase would start with students manipulating a chemical reaction. In this phase, students are exposed to three different reactions, each of which follow a similar mechanism, which is the production of hydrogen gas. The students will follow a reaction progression in which each reaction is more “violent” or “reactive” than the last. The difference between each reaction, which students will not realize at the time, is that a catalyst is added to the reactions observed (except for the first). The addition of a catalyst increases the rate of reaction, producing a more engaging reaction.

In the Gather portion of this Engage phase, students will investigate the evolution of hydrogen peroxide at different levels. Throughout this process, students will engage in self-driven or inquiry-based learning, which has been proven to increase student motivation and thinking (Jiang & McComas, 2015). Because some students may require extra support through this process, teaching suggestions have been added to scaffold learners and improve their
understanding of the phenomena. The final portion of the Gather sequence is to show students a reaction that produces a more interesting product to drive student questions and provoke thought about patterns in each investigated reaction.

The patterns will be further explored as part of the Reason sequence. In this case, students will work together to find similarities and differences in the reactions. The analysis of the reactions will be used to develop reasoning skills and provoke discussion, both of which merit increased understanding of material (Liu & Lawrenz, 2018). The class discussion will serve as a means for students to teach and learn from each other about what they visualized with the reactions. The goal is for students to recognize that the addition of some substance to the reactions is what caused the phenomena. Furthermore, students will be led to think about what other changes could be made to the reactants to produce such changes.

The last sequence, which involves argumentation, is the Communicate portion of this phase. According to Osborne et al. (2016) argumentation is one of the most important aspects of science learning. Its inclusion as part of the Gather sequence is for students to engage in thought about collision theory and think about chemical reactions relate to their lives. Students will be led to think about real-world examples of changes in reactions and how they could be investigated to further drive learning in this unit.

<table>
<thead>
<tr>
<th>Explore Phenomena 1</th>
<th>Student Science Performances</th>
</tr>
</thead>
<tbody>
<tr>
<td>In the Explore phase, students should gather information and data to develop evidence that supports explanations for the phenomenon from the Engage phase using related phenomena. Performances provide students with experiences that increase understanding of material while demonstrating their ability to make</td>
<td>Analogous Phenomenon: How can the lifespan of a glow stick be increased?</td>
</tr>
<tr>
<td>Gather:</td>
<td></td>
</tr>
<tr>
<td>Class Discussion</td>
<td>• How can a glow stick be manipulated to increase the time for which it glows without ruining the glow stick?</td>
</tr>
<tr>
<td></td>
<td>• How can the environment be changed to cause such changes?</td>
</tr>
</tbody>
</table>
sense of phenomena. Students should experience investigations, creating explanations, observing changes, and developing science-based abilities.

Teacher Actions:
The teacher’s role is to guide students throughout this learning process while promoting the use of crosscutting concepts to learn disciplinary core ideas.

- What changes might we expect to see at the atomic level?

1. Students plan and conduct an investigation to gather evidence on temperature changes and the patterns evident as they relate to reaction rates.

Teaching Suggestions:

- During the Engage phase, students will have developed the notion that temperature can alter the rate of reaction. Because other factors, such as the concentration, a catalyst, and surface area cannot be altered without ruining the integrity of the glow stick, temperature should be the only modification investigated.
- A quick investigation on temperature involves placing Alka Seltzer tablets in different temperature water. This can be used for students to gather data and develop a hypothesis about increasing the lifespan of a glow stick.

Reason:

2. Students develop an explanation for the changes exhibited in the Alka Seltzer reactions as a result of change in temperature.
3. Students develop a hypothesis about how to increase the lifespan of a glow stick based on patterns in temperature changes and reaction rates.

Teaching Suggestions:

- Students should be led to think about the speed of the particles (energy) and how this influences a reaction.
- Questions to consider:
  - How is the reaction influenced by cold temperatures? Hot temperatures?
  - What does changing the temperature do to the speed of the particles?
  - How might this influence a reaction?
  - How can these explanations be related to a glow stick?

Communicate:

4. Students construct a model to exhibit the changes that would result in a glow stick due to temperature differences.

Teaching Suggestions:

- Students will not know the chemical makeup of a glow stick, nor will they understand the reaction mechanisms involved in such a reaction. Instead, they should develop a particle model to demonstrate the differences in reactions between a glow stick in hot temperatures and a glow stick in cold temperatures.
- Ask students to whiteboard this and share with the class.
- Differences should be noticed in the speed of the particles and the number of collisions.

Class Discussion:
Students share their models and critique each other.

Demonstration involving glow stick plunged in cold water vs. hot water can be completed afterwards.

Explore 1 Rationale:

Each of the Explore phases is meant to build on questions drawn from students during the Engage phase. Furthermore, students will continue to focus on phenomena related to that from the Engage experience to continue developing an understanding of the disciplinary core ideas involved (Moulding & Bybee, 2017). In the first Explore phase, students will investigate temperature and how that influences reaction rate. Once again, they are tasked with investigation through a hands-on activity and then they are required to apply what they learned to a phenomenon familiar to them: the glow stick. At the end of this phase, students are asked to make a prediction as to how they can prolong the life of a glow stick using experimental prove. Some students may have previously been told that keeping glow sticks in a freezer prolongs their lives; however, they may not know why. This phase specifically explores how energy influences a reaction.

During the Gather sequence of this phase, the students will engage in an inquiry-based exploration of temperature. The students are led towards developing the investigation themselves and should collect the data they believe is necessary for understanding the phenomena. Because glow sticks are not easily manipulated, the students should focus on the aspect of temperature; however, if students inquire about the size or amount of liquid in the glow stick, make the comment that we do not want to change the glow stick itself. Allowing this discussion of how and what to investigate promotes student inclusion in the process as well as the nature of science to further foster learning (Michel & Neumann, 2016).
Reasoning throughout this phase will be focused on energy and how it can change a chemical reaction. Students have previously learned how energy influences particles, so they may be led into understanding how energy can influence a chemical reaction. This would be the first major idea or factor the students begin to investigate in collision theory. Students could also use this section to think about particle orientation in reactions. It may take some scaffolding to move forward, making teaching suggestions necessary. Students will be specifically analyzing their results and applying them to the glow stick phenomena to continue their three-dimensional learning (Plummer & Small, 2018).

Lastly, students will construct models to Communicate their understanding of the phenomena. In this case, students should be able to show how temperature directly influences the particles and ultimately the reaction. Engaging in a class discussion where students critique and learn from each other further builds on the idea of argumentation and its ability to increase understanding (Sampson & Blanchard, 2012). The class discussion should also be used to introduce the idea of collision theory and explain how energy is one of the three major factors. Afterwards, with time permitting, student predictions could be investigated by performing a demonstration to show how changing the temperature influences a glow stick. Otherwise, students could be told to assess their predictions outside of class.

<table>
<thead>
<tr>
<th>Explore Phenomena 2</th>
<th>Student Science Performances</th>
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</thead>
<tbody>
<tr>
<td>In the Explore phase, students should gather information and data to develop evidence that supports explanations for the phenomenon from the Engage phase using related phenomena. Performances provide students with experiences that increase understanding of material while demonstrating their ability to make sense of phenomena.</td>
<td><strong>Analogous Phenomena:</strong> Metals react with acids to produce a salt and hydrogen gas at different rates.</td>
</tr>
</tbody>
</table>
| **Gather:** | **1. Students** design and conduct an investigation to determine changes in reaction rate of an acid and a metal.  
2. Students obtain information about patterns in reaction rate based on different |
Students should experience investigations, creating explanations, observing changes, and developing science-based abilities.

**Teacher Actions:**
The teacher’s role is to guide students throughout this learning process while promoting the use of crosscutting concepts to learn disciplinary core ideas.

**concentrations** of acid and the **surface area** of the metal.

**Teaching suggestions:**
- Students may want to pursue changing the temperature. Acknowledge that this would likely work; however, it was previously tested.
- Provide students with the necessary materials to elicit thinking about surface area and concentration: various concentrations of acid, metal samples that are easily manipulated to change surface area.

**Reason:**

3. Students analyze the data to develop an explanation for the changes in reaction rates as a result of surface area and concentration manipulation.

**Teaching suggestions:**
- Students should be led to think about frequency of collisions and contact in reactions (orientation)
- Questions to consider:
  - How does increasing the surface area alter the reaction?
  - How does increasing the concentration of the acid alter the reaction?
  - Which conditions resulted in the quickest reaction? Slowest?
  - What does this say about the necessary conditions for a chemical reaction to occur?

**Communicate:**

4. Students construct a model to provide an initial explanation for the patterns exhibited in reaction rates with changing surface area and concentration.

**Teaching suggestions:**
- Students should draw particle models and think about how surface area and concentration could be varied.
- Ask students to whiteboard this and share with the class.
- Discuss optimal ways for representation.

**Class Discussion:**
- Students share their models and critique each other.

*Question to think about: Why don’t soda cans break down?*

**Explore 2 Rationale:**

In the second Explore phase, students investigate how concentration and surface area influence the rate of a reaction. The concentration and surface area investigated using an acid and a metal, which is a hands-on investigation. Once again, the phenomena are related to collision...
theory. In this case, the ideas in this lab will build upon the variable of number of collisions per unit time and orientation in a reaction. Students will analyze their results after completing their investigation and then they will construct a model to provide an explanation of what is happening at the particle level. Afterwards, students should discuss with and critique each other to determine the best way to represent what is transpiring as concentration and surface area are altered.

During the Gather section, students should be led to focus on concentration and surface area in their investigation. Because students already know that temperature would change the rate of a reaction, such an investigation should be simply discussed. Prompt the students to describe how they could change surface area and concentration while they perform their reactions and what sorts of data would need to be collected. Doing so would promote an inquiry-based investigation that fosters student learning and uses the teacher as a support rather than a guide (Gillies & Nichols, 2015). If students have trouble changing the surface area of the metal being used, a substitute would be to use a crushed versus a whole Alka Seltzer tablet.

As part of the Reason section, students will specifically think about the number of collisions per unit time during a reaction. While this variable may have been touched by some of the students in the previous Explore phase, many students may not recognize its importance until now. Students could be further prompted to think about how temperature also influences the number of collisions per unit time if it was not previously discussed. The discussion can be aided with prompting questions should students struggle to hold a meaningful conversation. The end goal is to develop an understanding that promotes the use of engineering practice through the creation of a model (Berland et al., 2014).

The model constructed in the Communicate section should further expand student
understanding of collision theory with the focus being on collisions per unit time and particle orientation. The particle orientation idea may need more prompting to draw out of students. At this point, students should then know the three major variables connected to reactions in collision theory. This can be enhanced with the discussion/argumentation that ensues.

If the class contains students who finish work quickly or are interested in learning more about science and the real-world, a question to pose at the end of the class could involve the breakdown of soda cans (King & Henderson, 2018). After this activity, students should conclude that acids break down metals. Carbonic acid is found in soda, yet the cans do not fall apart. Why is this the case?

<table>
<thead>
<tr>
<th>Explore Phenomena 3</th>
<th>Student Science Performances</th>
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<tbody>
<tr>
<td>In the Explore phase, students should gather information and data to develop evidence that supports explanations for the phenomenon from the Engage phase using related phenomena. Performances provide students with experiences that increase understanding of material while demonstrating their ability to make sense of phenomena. Students should experience investigations, creating explanations, observing changes, and developing science-based abilities.</td>
<td><strong>Analogous Phenomena: Reactions occur at different rates depending on the presence of a catalyst.</strong></td>
</tr>
<tr>
<td><strong>Teacher Actions:</strong> The teacher’s role is to guide students throughout this learning process while promoting the use of crosscutting concepts to learn disciplinary core ideas.</td>
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**Gather:**

1. Students investigate how the addition of a catalyst changes the rate of reaction.
   a. Students perform an experiment in which they place aluminum foil in a cup and pour Copper II Sulfate into the cup.
   b. Students manipulate the reaction by adding salt to the solution in the cup.
   c. Students read the following article about catalysts: [https://www.ck12.org/c/physical-science/catalyst/lesson/Catalysts-MS-PS/](https://www.ck12.org/c/physical-science/catalyst/lesson/Catalysts-MS-PS/)

**Teaching Suggestions:**

- Students should relate this activity to the one previously completed during the Engage phase. In this reaction, the salt acts like a catalyst, much like the yeast did.

**Class Discussion:**

- How was this reaction similar and different from the reactions involving hydrogen peroxide?
- What information have we now learned about catalysts?
- How are catalysts used in the human body?
Reason:

2. Students develop an explanation for how catalysts change chemical reactions at the atomic level.

Teaching Suggestions:

- Students should think about how catalysts affect the energy required for reactions.

Communicate:

3. Students create a model (in the form of a potential energy diagram) to express the changes that occur in a reaction.

Class Discussion:

- Students share their models and critique each other.

Explore 3 Rationale:

At this point, students understand that energy is required in chemical reactions and they should know that catalysts exist. They may not, however, recognize how they truly influence a reaction. This Explore phase is meant to address that. By the end, they should be able to develop a model that shows how catalysts manipulate the energy required for a reaction. Students will perform an investigation and relate it to previously done work as well as build literacy skills through a reading. As it pertains to collision theory, students will be able to discuss how catalysts lower the energy needed for a reaction.

The Gather section of this phase is structured a little differently than the previous sections due to the complexity of catalysts and the inability to visualize the changes that occur at a particle level. Thus, a reading is provided to students to gain background information on catalysts and activation energy. For some students, a reading guide may be necessary to complete this phase and gain a proper understanding of a catalyst’s role in a reaction. Students will still perform a hands-on investigation to gain more experience with catalyst-driven reactions.
Reasoning will require students to think about their previous experiences in the Engage phase. They should think about crosscutting concepts through patterns and develop conclusions based on energy changes (Chesnutt et al., 2019). At this point, students should be able to conclude that catalysts decrease the energy requirement for a reaction to occur, thus providing an alternative pathway for the reaction.

After the Gather and Reason sections, students will be able to develop a model that demonstrates how catalysts modify reactions. Continued conversation can promote learning from each other and further modification of student models (Kern & Crippen, 2017). In doing so, students will have a basic understanding of the three major tenets of collision theory. Further learning would be used to expand on factors that affect reaction rates based on collision theory.

<table>
<thead>
<tr>
<th>Explain Phenomena</th>
<th>Student Science Performances</th>
</tr>
</thead>
<tbody>
<tr>
<td>Students continue to use 3D learning in order to provide explanations for the phenomena that have been investigated thus far. They should be able to connect crosscutting concepts and disciplinary core ideas together to provide such explanations. Class discussion is imperative to ensure learning and promote collaboration.</td>
<td>Analogous Phenomena: Pressure and mixing are other variables that can be manipulated to alter the rate of a reaction.</td>
</tr>
<tr>
<td>Teacher Actions: The teacher elicits student explanations of prior phenomena and phases to lead students into another related phenomenon. The communication piece of this phase can be utilized as a formative assessment. If necessary, the ideas from this phase and the previous phases should be revisited to reinforce understanding of the concepts.</td>
<td>Reason:</td>
</tr>
<tr>
<td></td>
<td>1. Students develop an argument as to why pressure and mixing are variables that cause changes in reactants that result in an altered rate of a reaction.</td>
</tr>
<tr>
<td>Teaching Suggestions:</td>
<td></td>
</tr>
<tr>
<td>• Students should think about energy, orientation, and collisions of particles. • Pressure only influences reactions involving gases while mixing influences reactions involving at least one liquid or solution.</td>
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</tr>
<tr>
<td>Class Discussion:</td>
<td></td>
</tr>
<tr>
<td>• Think, Pair, Share • How does pressure influence the particles? • How does pressure influence a chemical reaction? • How does mixing influence the particles? • How does mixing influence a chemical reaction? • What aspects of collision theory are affected by these variables?</td>
<td></td>
</tr>
</tbody>
</table>
Communicate:

2. Students construct an argument in the form of a written paragraph and support it using experimental evidence to describe what changes mixing and pressure cause to change the rate of reaction.

**Essential Content:** Collision Theory explains that reactions require specific orientations of molecules, adequate energy, and a sufficient number of collisions in a period of time and manipulating this can modify reaction rates.

**Explain Rationale:**

During the Explain phase, students are required to express their understanding of the phenomena from the Engage and Explore phases through a formative assessment (Sickel et al., 2013). At this point in the learning process, students have covered various aspects of Collision Theory through variables that directly influence collisions, orientation, and energy. Utilization of pressure and mixing requires students to think about how the reactants are manipulated. Such manipulations result in changes in reaction rate and students must deduce this based on what they have previously learned (Waldrip & Prain, 2017). Being able to cite evidence using previous labs and learning allows them to make connections through writing.

In this phase, the Gather section is not necessary because students gained the knowledge they needed through the Engage and Explore phases. They have previously talked about pressure and from experience in life, they have an idea of what mixing does to a substance. Moving on to the Reason section, students will have to think about how changing pressure and mixing of reactants can change the reactions at a particle level. They will then use an engineering practice
to connect the core ideas and crosscutting concepts to make sense of how reaction rates are influenced (Wyner & Doherty, 2017). This is done in groups so that students could bounce ideas off each other.

During the Communicate section, students will create a written argument based on their discussions to demonstrate individual understanding of the phenomena. While most of this learning segment has been based on discussion and hands-on learning, it takes a different set of skills to communicate through writing as well, thus the inclusion as a formative assessment (Herman et al., 2012).

<table>
<thead>
<tr>
<th>Formative Assessment for Student Learning</th>
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<tbody>
<tr>
<td><strong>Elicit Evidence of Learning:</strong> Students construct an argument in the form of a written paragraph and support it using experimental evidence to describe what changes mixing and pressure cause to change the rate of reaction.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Evidence of Student Proficiency</th>
<th>Range of Typical Student Responses</th>
<th>Acting on Evidence of Learning</th>
</tr>
</thead>
<tbody>
<tr>
<td>For chemical reactions to occur, the molecules of a reactant must possess sufficient energy to exhibit a collision with a particle of another reactant in a specific orientation. These three major variables (energy, collisions, and orientation) serve as the base for Collision Theory, which is used to predict the rate of a chemical reaction. Energy, collisions, and orientation can be influenced by various factors, such as temperature, pressure, concentrations of reactants, mixing, surface area, and the addition of a catalyst.</td>
<td><strong>Full Understanding</strong> - Collision theory states that the rate of a reaction can be influenced by the energy of the particles, orientation of the particles in collisions, and the number of collisions per unit time. This was noticed when we increased the temperature, surface area, concentration, and added a catalyst to different reactions. Increasing the pressure of a system will decrease its volume (temperature remains the same) and result in increased frequency of collisions between moving particles. Increased frequency of collisions will make the reactants more likely to experience collisions with proper orientation per unit time. This would only be experienced by gases. Mixing creates an increase in the frequency of collisions with particles. Much like pressure, this results in a higher chance of a collision with proper orientation per unit time.</td>
<td><em>(What will students with partial and limited understanding do before moving on to the Elaborate Phase?)</em> Students with limited understand would complete the following simulation activity: <a href="https://teachchemistry.org/periodical/issues/may-2018/reaction-rates">https://teachchemistry.org/periodical/issues/may-2018/reaction-rates</a>. In this simulation, students will analyze graphical data to determine how different variables influence reaction rate. Upon completing the simulation, students will read the following article that...</td>
</tr>
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</table>
Depending on the reactants being mixed, it may also result in increased surface area in contact.

**Partial Understanding** -
Increasing the pressure of a system will result in an increased rate of reaction. Mixing reactants would also increase the rate of a reaction. These two arguments are based on the idea that Collision Theory states the rate of a reaction can be influenced by the energy of the particles, orientation of the particles in collisions, and the number of collisions per unit time. Altering the pressure and/or mixing the reactants would result in a change of one of these three factors.

**Limited Understanding** –
Changing the pressure of a system would result in a changed rate of reaction. Mixing the reactants of a reaction would also result in a change in reaction rate.

summarizes each of the variables that influence reaction rates.


Students with partial understanding need only read the article, unless they would like to complete the simulation as well.

In order to move on to the Elaborate phase from this point, students will then answer questions based on the ideas of Collision Theory to provide evidence of growth and understanding.

Also, include a one-on-one discussion with students.

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**Formative Assessment Rubric Rationale:**

The formative assessment is constructed as part of the Explain phase to demonstrate student learning throughout the Engage and Explain phases (Moulding & Bybee, 2017). In this case, students explain how pressure and mixing reactants are related to collision theory. Students are connecting all three dimensions of science learning through argumentation and reasoning. Doing so promotes a more effective expression of the skills and knowledge learned throughout the initial 5E Phases (Gotwals & Songer, 2013).

This rubric details what information students should know at this point in the “Evidence of Student Proficiency” section. In it, collision theory is described, as well as the factors that students have investigated. Thus far, students have developed an idea of how collisions, orientation of particles, and energy correspond to collision theory and reaction rates. They have
also looked at specific factors that influence reaction rate, which are temperature, pressure, mixing, surface area, concentration, and addition of a catalyst.

In the “Range of Typical Student Responses” section, sample arguments are constructed based on three levels of understanding: full, partial, and limited. Students with full understanding will be able to adequately demonstrate the knowledge cited in the Evidence section, while a student with limited understanding will not. A student with partial understanding would fall in between. Should a student demonstrate partial or limited understanding, it would be necessary to provide extra materials to increase their understanding to satisfactory levels. This is described in the “Acting on Evidence of Learning” section.

Students who require extra learning, or even students who want more information to look at, are provided online materials to develop a better understanding of collision theory. This is in the form of a simulation, a reading, and an online test generator. Gryczka et al. (2016) cite the use of online laboratory activities as beneficial for student understanding, so using a simulation first might be effective in providing students with more evidence of reaction changes. Further scaffolding to increase learning through the reading will help students to build on ideas reinforced in the simulation (Kang et al., 2014). Lastly, students will demonstrate their learning using a Castle Learning assignment and a one-on-one discussion with the instructor. This method provides students an opportunity to express their learning through different representations.

<table>
<thead>
<tr>
<th>Elaborating Scientific Concepts and Abilities</th>
<th>Student Science Performances</th>
</tr>
</thead>
<tbody>
<tr>
<td>The students experience ideas that are new but related to the previous phenomena. The material is meant to promote extension of learning and may relate to real-world application.</td>
<td><strong>Analogous Phenomena: Polyurea (Line-X) Reaction</strong> – How do you mix the two ingredients of the coating in a way that would produce a usable substance? Relate this to Collision Theory.</td>
</tr>
<tr>
<td><strong>Gather:</strong></td>
<td></td>
</tr>
</tbody>
</table>


### Teacher Actions:
The teacher continues to act as a guide for learning while students are exposed to a phenomenon that challenges them to think critically about previous ideas. Students may need to conduct an investigation, collaborate, and find information through various means.

### 1. Students conduct an investigation to determine patterns in Line-X that are consistent with previously completed investigations and the rate of reaction.
   a. Students watch the following video until about 4 minutes in: [https://www.youtube.com/watch?v=DWkYRh6Oxy8&t=338s](https://www.youtube.com/watch?v=DWkYRh6Oxy8&t=338s)
   b. Students browse the internet for real-world application of Collision Theory (Line-X is off limits)

### Teaching Suggestions:
- Explain to students that many products in the world are created through chemical reactions under specific conditions.
- Line-X is most typically used as a truck-bed liner, but it has many other purposes.
- Students should think about the variables (temperature, pressure, particle size, etc.) that we have investigated thus far.

### Class Discussion:
- What things would you like to know about the components of Line-X?
- How can we spread the material without it solidifying?
- Why can’t we simply mix the two reactants together?
- What other Collision Theory applications are there?

### Reason:

2. Students develop an explanation based on evidence from prior activities and research for how Line-X exhibits patterns consistent with collision theory.

### Teaching Suggestions:
- Students should think about the conditions necessary to combine the ingredients quickly and effectively.
- Mention that it may be necessary to first develop a device to spread the ingredients.

### Communicate:

3. Students develop a model to illustrate how they would use patterns and collision theory to combine the ingredients to make Line-X coatings.

### Teaching Suggestions:
- Models should consist of a labelled apparatus and necessary captions.
- Models should be based on Collision Theory and evidence from
Elaborate Rationale:

In the Elaborate phase, students apply their knowledge from earlier phases to a phenomenon that extends their understanding of the core ideas covered (Moulding & Bybee, 2017). For this learning segment, the Elaborate phase requires students to apply the ideas of collision theory to a real-world example: Line-X, which is a durable substance used to create bedliners, among other things. Students learn about what Line-X is and what it is composed of. From there, students are tasked with developing a plausible method for combining the ingredients of Line-X to make a usable material. A model is then developed to demonstrate understanding of the phenomenon.

The Gather section of this phase begins with a video to introduce the Line-X phenomenon. Students are posed with the question of how to combine its ingredients and then find evidence from various sources of how collision theory is used in the real-world. Providing students with this opportunity allows them to expand on their knowledge of collision theory and find information necessary for the Reason portion of this phase. This problem-based approach is open-ended, which promotes accountability from the students and allows them to drive their own learning (Kang et al., 2012).

After gathering the necessary information, students will develop an explanation of how Line-X reactions apply to collision theory through Reasoning. This allows the students to expand on their knowledge from the previous phases. Students will then have the knowledge necessary for applying collision theory to a real-world problem.
Lastly, students will develop a model for how to combine the two reactants for Line-X and then analyze the work of others. This occurs during the Communicate section and provides a reason for argumentation. While work is shown, it may be necessary for students to argue for their models while inquiring about others. As a wrap-up to this activity, the final half of the Line-X video could be shown to explain how Line-X is truly manufactured.

<table>
<thead>
<tr>
<th>Evaluating Learners</th>
<th>Student Science Performances</th>
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<tbody>
<tr>
<td>Throughout this process, students have been presenting their ideas using multiple representations. They have also received feedback on their abilities to elaborate on certain ideas. The Evaluate phase requires students to use crosscutting concepts to connect the disciplinary core ideas covered throughout the learning segment while applying them to another phenomenon that is related to the previous phenomena. Students apply their learning from previous phases to make sense of a real-world catastrophe: The demise of the Hindenburg airship.</td>
<td><strong>Analogous Phenomena: In 1939, the LZ 129 Hindenburg Airship caught fire and was destroyed New Jersey, marking the end of the airship era.</strong></td>
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<td><strong>Gather:</strong></td>
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<tr>
<td>1. Students <strong>obtain information</strong> about how an airship works and relate it to <strong>patterns</strong> found in <strong>collision theory</strong> to determine what dangers are possible during flight.</td>
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<td><strong>Teaching Suggestions:</strong></td>
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<tr>
<td>• Students will likely not know about the Hindenburg or what an airship is. Showing pictures and a video may be helpful (<a href="https://www.youtube.com/watch?v=CgWHbpMVQ1U">https://www.youtube.com/watch?v=CgWHbpMVQ1U</a>)</td>
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<tr>
<td>• Students may require extended time to find important information about airship function. For students who need scaffolding, providing sources may be necessary.</td>
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<tr>
<td><strong>Reason:</strong></td>
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<tr>
<td>2. Students <strong>develop an argument</strong> for how <strong>patterns</strong> found in everyday <strong>chemical reactions</strong> can result in such a catastrophic event.</td>
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<td><strong>Teaching Suggestions:</strong></td>
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<tr>
<td>• At this point, students understand Collision Theory and factors that can change reaction rates. Students should be asked to think about how such factors could influence the combustion of the airship and its demise.</td>
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<tr>
<td>• Questions to think about:</td>
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<tr>
<td>o What patterns are noticed in all chemical reactions?</td>
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<tr>
<td>o What conditions are required for a reaction to occur?</td>
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<tr>
<td>o Based on what you know about reactions, how could the airship have initially caught fire?</td>
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<tr>
<td>o How did these conditions result in destruction?</td>
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<tr>
<td><strong>Communicate:</strong></td>
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</table>
Evaluate Rationale:

In the Evaluate phase, students express their understanding of the material explored throughout the previous E’s of the 5E Sequence (Moulding & Bybee, 2017). At this point, students should have developed the knowledge required to describe collision theory and make conclusions about reaction rates based on changes with specific variables. This phase allows students to demonstrate that knowledge using a real-world phenomenon: The destruction of the Hindenburg Airship. Students may or may not know about the Hindenburg from history, so a little backstory may be necessary; however, the goal will be for the students to use their knowledge about collision theory to provide a possible explanation for the demise of the airship.

Students will Gather information about the Hindenburg and other airships, in general, to gain a necessary understanding of the background and function of such transportation devices. This information is then used to connect patterns between collision theory and possible dangers during flight of an airship. Doing so will require research from various sources, as well as knowledge of collision theory to make connections, thus relating the phenomenon back to the learning segment.

After applying collision theory to airships, students will Reason how chemical reactions found in everyday life can result in catastrophic events. Further reasoning occurs as students connect the patterns to possible causes of destruction in the case of the Hindenburg. Because the cause of the Hindenburg destruction is unknown, there is not a single, correct answer. This provides students the ability to be creative to a certain degree.
The connections made by the students are communicated in the form of a written document that explains how collision theory contributed to the destruction. This document serves as the formative assessment and allows the teacher to gain an understanding of the learning that occurred throughout the 5E/GRC sequence.

<table>
<thead>
<tr>
<th>Evidence of Student Proficiency</th>
<th>Range of Typical Student Responses</th>
<th>Acting on Evidence of Learning</th>
</tr>
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<tbody>
<tr>
<td>The LZ 129 Hindenburg airship went up in flames and was destroyed in 1939 while in the United States. The initial ignition and fuel for the fire are only speculated and no true explanation is known. Analysis of this event provides students with the ability to apply Collision Theory and reaction rate ideas to a real-world catastrophe. Because the explanations behind the destruction are only hypotheses, there is not a correct answer. The idea is for students to construct a logical argument based on what they learned from this sequence.</td>
<td><strong>Full Understanding</strong> - Combustion requires a source of fuel and involves a chemical reaction. Because of this, the reactants must have been colliding in proper orientations with enough energy. Since the airship was able to travel without such an explosion to begin with, something must have happened at the time of the fire. Based on investigations in class, it can be postulated that either a source of energy or a catalyst was introduced to the molecules in the airship, resulting in the initial ignition. This would have provided the reactants with the energy necessary to initiate a chemical reaction. Because the air in the ship itself could act as a fuel source, the rest of the ship was able to catch fire. The reactants would need to continue colliding with enough energy, which could be provided from the energy emitted by the fire itself. Furthermore, the fact that the fuel is a gas allows the reactants to mix more easily and collide with specific orientations because of the increased surface area and concentration.</td>
<td>Students with a limited or partial understanding should read the following article: <a href="https://www.cdli.ca/sampleResources/chem3202/unit01_org01_ilo03/b_activity.html">https://www.cdli.ca/sampleResources/chem3202/unit01_org01_ilo03/b_activity.html</a> They may also benefit from watching the following video: <a href="https://www.youtube.com/watch?time_continue=2&amp;v=OttRV5ykP7A">https://www.youtube.com/watch?time_continue=2&amp;v=OttRV5ykP7A</a> After doing so, students should engage in a one-on-one discussion with the teacher to express what they have learned.</td>
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</tbody>
</table>
investigations in class, it can be postulated that either a source of energy or a catalyst was introduced to the molecules in the airship, resulting in the initial ignition. Continued burning and the destruction of the ship may have been the result of increased temperatures causing more of the reactant particles to collide with enough energy. It should also be mentioned that the air in the ship itself could be a fuel. Because the particles are gaseous (large surface area) and concentrated, the reaction rate would be relatively fast.

**Limited Understanding**

The fire on the Hindenburg must have been caused by a spark or ignition source, which set a chemical reaction in motion. This would have been the result of particles colliding with enough energy and with proper orientation. The material of the air ship is flammable so after the initial fire, it would be easy for the rest of it to light.

**Formative Assessment Rubric Rationale:**

Much like the formative assessment rubric for the Explain phase, this table provides the teacher with an understanding of student learning. This rubric is based on the assessment from the Evaluate phase and details the overall expectation from the students in the “Evidence of Student Proficiency” section. In it, a brief background of the Hindenburg explosion is provided, as well as how it relates to collision theory.

Students are likely to have varying responses that align with those described in the “Range of Typical Student Responses” section. Students should be able to relate collision theory and the major variables of energy, collisions, and orientation to the Hindenburg explosion. The degree of connections made between the two provides a means of assessment of student knowledge. Should students not have a full understanding of the material, they can be provided with extra support to enhance their learning.
The extra support is found in the “Acting on Evidence of Learning” section. Students who require this support will read another article about collision theory and factors that affect it. They will also watch an animated video that provides an explanation of the topic. Afterwards, students will be asked to have a discussion with the teacher about collision theory and how it can apply to real-world situations.

**Student Prompts:**

The following student prompts are meant to be provided to the students throughout the learning segment. This can be done in the form of a projection or on paper. This allows the students to see what is expected and questions can be asked as needed.

- **Engage**

  **Phenomenon 1:** Hydrogen peroxide reacts differently under varying conditions to produce different amounts of oxygen.

  **Group Performance**
  1. **Carry out an investigation** to obtain evidence for causes of differences in the reactions of hydrogen peroxide.
     a. Materials: 3% hydrogen peroxide, test tube, unknown substance
  2. **Ask questions** about patterns in present in the chemical reaction rates of hydrogen peroxide and elephant toothpaste.
     a. Elephant Toothpaste Demo
  3. **Compare and contrast** patterns presented in the three chemical reactions observed.

  **Individual Performance**
  4. **Develop an explanation** for causes of the differences in reaction rates.

  **Group Performance**
  5. **Argue** about patterns in chemical reactions and how they can be manipulated to investigate factors that influence reaction rates.

- **Explore 1**

  **Phenomenon 2:** How can the lifespan of a glow stick be increased?

  **Group Performance**
  1. **Plan and conduct an investigation** to gather evidence on temperature changes and the patterns evident as they relate to reaction rates.
2. Develop an explanation for the changes exhibited in the Alka Seltzer reactions as a result of change in temperature.
3. Develop a hypothesis about how to increase the lifespan of a glow stick based on patterns in temperature changes and reaction rates.

**Individual Performance**
4. Construct a model to exhibit the changes that would result in a glow stick due to temperature differences.

**Class Discussion**

**Explore 2**

**Phenomena 3: Metals react with acids to produce a salt and hydrogen gas at different rates.**

**Group Performance**
1. Design and conduct an investigation to determine changes in reaction rate of an acid and a metal.
2. Obtain information about patterns in reaction rate based on different concentrations of acid and the surface area of the metal.
3. Analyze the data to develop an explanation for the changes in reaction rates as a result of surface area and concentration manipulation.

**Individual Performance**
4. Construct a model to provide an initial explanation for the patterns exhibited in reaction rates with changing surface area and concentration.

**Class Discussion**

**Explore 3**

**Phenomena 4: Reactions occur at different rates depending on the presence of a catalyst.**

**Group Performance**
1. Investigate how the addition of a catalyst changes the rate of reaction.
   a. Materials: Aluminum foil, plastic cup, salt, Copper II Sulfate
   b. Read the following article about catalysts: https://www.ck12.org/c/physical-science/catalyst/lesson/Catalysts-MS-PS/
2. Develop an explanation for how catalysts change chemical reactions at the atomic level

**Individual Performance**
3. Create a model (in the form of a potential energy diagram) to express the changes that occur in a reaction.

**Class Discussion**

**Explain**

**Phenomena 5: Pressure and mixing are other variables that can be manipulated to alter the rate of a reaction.**

**Group Performance**
1. Develop an argument as to why pressure and mixing are variables that cause changes in reactants that result in an altered rate of a reaction.

Class Discussion

Individual Performance
2. Construct an argument in the form of a written paragraph and support it using experimental evidence to describe what changes mixing and pressure cause to change the rate of reaction.

Elaborate

Phenomena 6: Polyurea (Line-X) Reaction – How do you mix the two ingredients of the coating in a way that would produce a usable substance? Relate this to Collision Theory.

Group Performance
1. Conduct an investigation to determine patterns in Line-X that are consistent with previously completed investigations and the rate of reaction.
   a. Watch the following video until about 4 minutes in: https://www.youtube.com/watch?v=DWkYRh6OXy8&t=338s
   b. Browse the internet for real-world application of Collision Theory (Line-X is off limits)
2. Develop an explanation based on evidence from prior activities and research for how Line-X exhibits patterns consistent with collision theory.

Individual Performance
3. Develop a model to illustrate how they would use patterns and collision theory to combine the ingredients to make Line-X coatings.

Evaluate

Phenomena 7: In 1939, the LZ 129 Hindenburg Airship caught fire and was destroyed New Jersey, marking the end of the airship era.

Group Performance
1. Obtain information about how an airship works and relates it to patterns found in collision theory to determine what dangers are possible during flight.
2. Develop an argument for how patterns found in everyday chemical reactions can result in such a catastrophic event.

Individual Performance
3. Construct an explanation based on evidence for how patterns in collision theory could have contributed to the Hindenburg destruction
References


