

THE EFFECTS OF IMPLEMENTING SCIENCE AND ENGINEERING PRACTICES AND
CROSSCUTTING CONCEPTS ON STUDENT SCIENCE ACHIEVEMENT AND
ATTITUDES IN A HIGH SCHOOL CHEMISTRY CLASSROOM

by

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DEDICATION

I dedicate this paper to my family. They have helped shape me into the woman I am today and without their support and encouragement, I would be lost. First off, thank you to my Mom for patiently listening to the clack of my keyboard as I worked on this project on weekend visits home and for lending an ear when I needed to vent about the process. Thank you to my husband for giving me the space to work every night after school and for making this trip to Montana with me. Thank you to my dear sisters, who are my best friends. They are always there to encourage and support me in this journey called life. I also dedicate this paper to my nieces and nephews. I hope that this encourages them to pursue their education and to follow their dreams. Thank you to my colleagues at Marshall High School—Tracy, Angela, and Melyssa, who encouraged me to pursue higher education and have been sounding boards for my ideas and editors on my papers. Most importantly, thank you to my students! I appreciate how willing they have been to learn new things and to share their honest opinions about learning science. My favorite part of this project has been reading their responses. Lastly, I dedicate this paper to my Dad. If he were still here, I know he would be so incredibly proud to see me earn this master's degree.

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ABSTRACT

The Next Generation Science Standards have been the foundation of science education since their adoption in 2014. These standards are unique in that they do not focus solely on the content, but they take an integrated approach by interweaving Science and Engineering Practices (SEPs) and Crosscutting Concepts (CCCs) alongside traditional content standards to immerse students in all of the practices scientists use. Although these standards have been around for over a decade, many science classrooms continue to focus mainly on content and labs to learn science. This project set out to answer the question, How will explicitly teaching the SEPs and CCCs of the NGSS impact student science achievement and perceptions in a high school chemistry course? To investigate this question, students were taught about each SEP and CCC over a two-week unit and then these practices were incorporated into a content unit over the periodic table and trends. Achievement was measured using a pretest and posttest as well as multiple Likert scale surveys to gauge student familiarity with the SEPs and CCCs. The data were analyzed using mean, median, normalized gains, and thematic analysis. The results showed which SEPs and CCCs students were most familiar with and growth in familiarity after being explicitly taught these practices. Most students demonstrated medium to high gains from pre-to-post treatment. This study led to the conclusion that it would be best advised to start the year by introducing the SEPs and CCCs and integrating them throughout each unit as some units match up better with certain SEPs and CCCs than others. This study also showed that students had some awareness of what scientists do, but they identified lab work and analyzing data as the primary components of scientific work. They did not always identify the communicative piece of scientific work or the steps of doing a lab investigation.

CHAPTER ONE

INTRODUCTION AND BACKGROUND

Context of the Study

Marshall High School (MHS) is a public high school located in South Central Michigan. MHS is one of two high schools in the Marshall Public Schools District, the other being an alternative education opportunity high school. According to the principal, there are 824 students at MHS (D. Turner, personal communication, September 2024). In Michigan, high schools are categorized by their number of students. With 824 students enrolled, Marshall is considered a large class B school, with class A being the largest. Seventeen percent of students qualify for special education services with an identified disability (MI School Data, 2025). Twenty-two percent of the students identify as non-White. Socioeconomic status is a factor tied to student success, and 41% of the students are low income (Great Schools, 2024). Challenges at home present challenges within the classroom; nevertheless, Marshall High School has a 94% graduation rate (US News, 2023).

In the past, only 27% of our 11th grade students who take the Michigan Student Test of Educational Progress, or MSTEP, have been proficient in science compared to the statewide average of 40% (US News, 2023). The MSTEP was redesigned to align with the science practices and content outlined in the Michigan Science Standards (MSS) which are based on the Next Generation Science Standards (NGSS). Michigan adopted its version of the NGSS in 2015 (Michigan Department of Education, 2015). The NGSS are three-dimensional standards that focus on content with Disciplinary Core Ideas (DCIs), Science and Engineering Practices (SEPs),

and Crosscutting Concepts (CCCs). The science program at Marshall High School has traditionally placed little emphasis on two of these components—the SEPs and CCCs. The MSTEP asks 3D style questions that use all three components of the NGSS, and they do not focus solely on science content; rather, this test asks students questions where they need to read a real-life scenario or look at actual lab data to answer. The idea for my Action Research project stemmed from a desire to do more with the Next Generation Science Standards (NGSS) than simply focusing on content, which only encapsulates one dimension of the NGSS.

Our school has been focusing on ways to improve our MSTEP scores as part of our districtwide school improvement initiative with our curriculum director. We set a small goal to improve our scores by 4% and as a science department, and brainstormed ways to achieve this goal. One strategy that the science department identified was to implement more NGSS style 3D questions into our curriculum learning objectives for each content unit. We also brainstormed incentivizing the test, changing the testing time and locations, as well as having smaller class sizes to improve science discourse within our classes. However, many of these ideas were beyond our control, so changing how we present content and prepare students seemed like the best way to try to improve science achievement and understanding at MHS. For this reason, I decided to incorporate this school improvement goal into my Action Research project.

In my 14 years of teaching, I have taught science to over 1,400 students—primarily to freshmen in biology and sophomores in chemistry. I have observed that many students possess an attitude that they are only doing science when they are doing an actual laboratory exercise with chemicals. However, lab experiments are a small component of what actual scientists do on a daily basis. By explicitly teaching the SEPs and CCCs to students and having them identify

these components of science in their daily activities, my hope was that students would start to see science as something that occurs in settings beyond the lab and the classroom. My school's MSTEP scores clearly demonstrated a need to teach science content in the manner that the Next Generation Science Standards have proposed; therefore, I implemented an Action Research project that focuses on incorporating the SEPs and CCCs into daily curriculum.

Focus Question

My focus question was, How will purposefully teaching the Science and Engineering Practices and Crosscutting Concepts of the Next Generation Science Standards impact student achievement and perceptions/attitudes in a high school chemistry course?

CHAPTER TWO

CONCEPTUAL FRAMEWORK

The Scientific Method and its Limitations

The scientific method is often referenced as the series of sequential steps that scientists follow in order to investigate observed phenomena. In this process scientists ask questions, formulate hypotheses, investigate, and collect data. Data is then analyzed to form a conclusion (Hepburn & Andersen, 2021). All levels of science education have taught and used the components of the scientific method. This method has been mentioned in most, if not all, science textbooks and is used daily by engineers, researchers, scientists, and teachers (Windschitl et al., 2007). Windschitl et al. (2007) conducted research with newly graduated science teachers and found that most of these teachers used the scientific method as an instructional basis in their science classrooms. While the scientific method outlines science sequentially into a series of steps, science is not a linear process. Rather, it is a collection of processes that focus on what was learned and how it was learned, not necessarily the sequence of events (Hepburn & Andersen, 2021). The scientific method is not a fair account or accurate description of what all scientists universally do. Scientists are the products of their unique research environment and specialty; therefore, a singular method is not universal (Skinner, 1956; Windschitl et al., 2007).

The Next Generation Science Standards

Historically speaking, the United States has often lagged behind other countries in encouraging students to pursue a career in science, but the United States also has a deep desire to compete with other countries for technological advances (Shapiro & Kraus, 2021). Dating back

to the 1960s, there has been an educational shift in teaching the practices of science versus the scientific method (Bybee, 2011). The scientific community does not have a singularly defined scientific method. The method itself overlooks the importance of communicating information to the public and the scientific community (Schwarz et al., 2017). The Next Generation framework states at least eight times that, “there is no single, step-by-step (universal) scientific method” (McComas & Nouri, 2016, pg. 570). The Next Generation Science Standards (NGSS) are a blueprint for the best practices in science education to educate students to be strong in science. One of their primary focuses is to improve science education so that society will be more successful in making informed decisions in their everyday lives. Schwarz et al. (2017) pointed out that students are not in the classroom to simply absorb information from their teachers. Instead, students must do the work themselves to form their own knowledge about the phenomena that surround them in their everyday lives. Students cannot passively learn science; they need to be active participants in science.

The NGSS focus on the connection between science and engineering practices, disciplinary core ideas, and crosscutting concepts in order to achieve a broader understanding of the process of science, how science is communicated, and its concepts (National Research Council, 2012). These three areas, when combined, create performance expectations which lead to three-dimensional learning. The disciplinary core ideas (DCIs) form the science content, the science and engineering practices (SEPs) define how science is taught and what scientists do, and the crosscutting concepts (CCCs) bridge different disciplines together (Shapiro & Kraus, 2021). Grooms et al. (2015) advocate that the Standards are designed to connect the practices of the actual scientific community with the education students are receiving in the classroom. Many

of the DCIs and SEPs have been present in science education for decades but have been shifted to different grade levels and more current DCIs, such as climate change have been added. In addition, most of the SEPs have been taught in the past as part of a rigid scientific method (Shapiro & Kraus, 2021). One of the goals of the NGSS is to engage students in more depth and less breadth of content knowledge while increasing the number of activities in which students perform actual science practices (Guzules, 2024).

The Science and Engineering Practices

One of the primary components of the NGSS is the science and engineering practices (SEPs). The SEPs consist of practices that all scientists use during the process of science and that they use to communicate scientific information. These include asking questions and defining problems, developing and using models, planning and carrying out investigations, analyzing and interpreting data, using mathematics and computational thinking, engaging in argument from evidence, constructing explanations, and obtaining, evaluating, and communicating information. These practices by design are interconnected and best used as active engagement tools for students exploring the process of science. The vision of the SEPs is that they are taught and utilized across grade levels from kindergarten through 12th grade and that they can be used through the lens of science or engineering. When students are engaging with the science and engineering practices, they are working towards understanding scientific concepts by being engaged in the process of science (National Research Council, 2012).

The National Research Council (2012) differentiates between science and engineering in that science answers questions and engineering solves problems. The science and engineering practices are designed to be used as instructional strategies and learning outcomes in order to

teach students science (Bybee, 2011). The NGSS framework calls these eight scientific methodologies practices because students are performing inquiry-driven activities to learn content knowledge while practicing what scientists actually do. One of the focus points of the SEPs is to have students engaging in arguments based on evidence and making claims about observed phenomena (Reiser et al., 2012). According to the National Research Council (2012), when students are engaged in the SEPs to learn science content, it sparks their curiosity and helps retain student engagement.

Numerous examples of the science and engineering practices in action are readily available in academia. One example provided by Pasley et al. (2016) describes an investigation of chemical reactions in a high school chemistry course. The teacher had students perform a quick lab with antacid tablets in water. Then, the students asked questions and defined problems which led them to plan an investigation into reaction rates. After the experiment, they communicated and discussed their plans with the whole class. Students then performed the lab exercise, collected data, and shared that data with the class using mathematics and computational thinking. Lastly, students constructed an explanation that answered the question about the effects on reaction rates. In this one activity to investigate a single DCI, students engaged with at least five of the science and engineering practices including asking questions, planning and carrying out investigations, collecting and analyzing data, using mathematics and computational thinking, and communicating scientific information.

As states adopt the NGSS, their assessments have been updated to incorporate the SEPs, CCCs, and DCIs. An example of an interactive assessment that tests for three-dimensional knowledge was provided by Alonzo and Ke (2016). The researchers described an eighth-grade

assessment that evaluated knowledge of magnetic fields using different metal bars and magnets. Students had to plan and conduct an investigation to determine which bars were magnetic. Students made observations, collected data, and analyzed their data for patterns. Students then justified their reasoning and constructed an explanation for their identifications of the bars using evidence they collected in their experiments. Most of the SEPs were present in this performance task, including planning and carrying out investigations, engaging in argument from evidence, communicating information, analyzing and interpreting data, and using mathematics and computational thinking. However, the authors pointed out some limitations to this type of assessment and stated that more time is needed to be able to assess both content and practices simultaneously, rather than any independent performance task.

The Crosscutting Concepts

The authors of the NGSS framework envisioned the crosscutting concepts as ideas that connect science and engineering practices with science content that would be explicitly taught to students throughout K-12 education. (National Research Council, 2012). The crosscutting concepts (CCCs) include the investigation and use of patterns, cause and effect relationships, structure and function of systems, scale, proportion, and quantity, energy and matter, systems and system models, and stability and change (National Research Council, 2012; Fick, 2016). The purpose of the crosscutting concepts is to link together the science and engineering practices and content knowledge across science disciplines (Fick, 2016). The crosscutting concepts of the Next Generation Science Standards (NGSS) are designed to be used and integrated into the everyday lives of students but have been traditionally presented to honors or advanced students only. Teachers have struggled to successfully integrate the NGSS into their science curriculums. One

proposal for successfully integrating the CCCs is to treat them as science practices that students use every day and already have in their schema and to gather information from students on how they use each (Goggins et al., 2019). Cooper (2020) suggests that there are four different views to consider when using the crosscutting concepts. She stated that they can be used as “tools, lenses, bridges, or the rules of the game” (p. 903).

Research literature provides many examples of successful integration of crosscutting concepts in science classrooms. Goggins et al. (2019) provided an example of a fifth-grade classroom using garbage samples to investigate patterns and systems and system models. Students sorted the garbage according to their own standards established by a cooperative group discussion. Students found patterns based on similarities and differences amongst the items sampled. After using the SEP of engaging in argument from evidence to explain how their garbage changed over the course of two weeks, students worked together to brainstorm ideas of where their garbage goes in the real world for disposal. As a class, they constructed a concept map and flow chart model to show where their trash goes upon disposal from their schools, homes, and community.

Another classroom vignette showing the implementation of crosscutting concepts was researched by Pasley, et al. (2016). This study described the use of the crosscutting concepts and science and engineering practices in a high school biology classroom focused on genetics. In this classroom, the teacher had their students start the unit by constructing Punnett squares and analyzing them for patterns of inheritance. When looking for patterns, the students used the crosscutting concept of scale, proportion, and quantity to explain the results of the cross using ratios of dominant and recessive genes. Students then applied these ratios to a larger population

of plants and saw the same pattern. Students discussed the results of crosses to study the effects of a plant inheriting certain genes. This allowed them to see that the type of gene inherited at the microscopic level directly impacted the phenotype presented at the macroscopic level (Pasley et al., 2016).

A third classroom example of using the crosscutting concepts of system and system models was to explore the role of water in the Earth system and processes using the phenomenon of a watershed. The author tied this core idea in with the science and engineering practice of developing and using models. The teacher in the study explicitly taught the CCC to students so that it could be used as a tool to explain the phenomenon. The author shared three observations at the conclusion of the study. The CCCs can help students understand the content on a base level, students can use the CCC independently to add to their depth of knowledge, and students can apply the CCC to answer questions and wonderings about a subject. Depending on the crosscutting concept chosen, the unit design plan could have taken a different path. For instance, the CCC of matter and energy is important to understand the role that gravity plays on water flow as well as thermal energy in the water cycle. The author pointed out the importance of the lens used for each crosscutting concept as they are utilized in the classroom (Fick, 2016).

The crosscutting concepts have been difficult for educators to implement in a sequential manner from K-12. Some crosscutting concepts, such as patterns and cause and effect are taught evenly throughout all grades. Other crosscutting concepts such as scale, proportion, and quantity as well as structure and function are seldom taught in the lower elementary grades and are not practiced as frequently in comparison to the other crosscutting concepts in the secondary grades (Osborne et al., 2018). Shapiro and Kraus (2021) identified the crosscutting concepts of patterns

and systems and system models as the most used crosscutting concepts, whereas stability and change is the least used crosscutting concept. Cooper (2020) points out that the crosscutting concepts are often forgotten in the NGSS and have a less defined role than the science and engineering practices and disciplinary core ideas. She identifies three main issues with the implementation of the crosscutting concepts: they are misidentified as connections between science and other content areas, they are grouped together with little explanation for where each concept's origin lies and its importance, and they do not have a large depth of research that supports their use for making connections across all science disciplines.

Incorporating the SEPs and CCCs into a 3D Curriculum

Using the three dimensions of the NGSS lends itself to the best outcomes for understanding in a science classroom. Each dimension of the NGSS should be interconnected with another to ensure that students are experiencing a well-rounded science education. When a Disciplinary Core Idea (DCI) and a Crosscutting Concept (CCC) interact, the CCC helps to connect the more specific DCI to the world. When a DCI and Science and Engineering Practice (SEP) interact, the focus is to utilize practices that scientists use to investigate scientific content. When all three components of the NGSS interact, the standard is met (Houseal, 2016). According to Fick (2016), there has been more emphasis on the SEPs and DCIs to teach science standards, but the CCCs play a vital role in three-dimensional science education.

Brown et al. (2023) argued that teachers should use a backwards design model when designing lessons, should engage students in driving instruction, should enhance student ideas with activities and discussions, and should have students reflect on their own learning. They provide an example of a lesson that investigates the DCI of energy transfer using the classic

example of making ice cream in a coffee can. Throughout the lesson, the students use the SEPs of analyzing and interpreting data, using math and computational thinking, asking questions, and constructing explanations. The CCCs of patterns, cause and effect, as well as scale, proportion, and quantity are involved in investigating the given phenomenon (Brown et al., 2023). When engaging students in 3D learning using the CCCs, SEPs, and DCIs, it is important that students understand what each CCC and SEP entails before linking them together for 3D learning (Houseal, 2016). Bybee (2014) pointed out that the three dimensions should be integrated into a curriculum through the use of activities, simulations, and investigations that use all three components of the NGSS.

Research Conclusions

For decades, students have learned science as a series of facts and figures to be memorized and as a series of sequential steps to follow. The Next Generation Science Standards have been rolled out and implemented as a new method of teaching science for understanding the world around us and to engage students in the process of science. The NGSS consist of three components that when interwoven together, help students to not only learn the content of science, but also to think scientifically using the CCCs and SEPs in order to practice the methods that scientists use to collect data, analyze data, and disseminate information to the world. The NGSS grew from a need for new science standards that teach content while captivating students with the processes that scientists use. The NGSS encourage student engagement in science and promote the learning of not only science content, but also science best practices.

For the NGSS to be fully incorporated into the classroom, students must be explicitly taught what the SEPs and CCCs are to apply them to new content and situations. Research has

shown that using the SEPs and CCCs to learn scientific content is more immersive and interactive. Implementing these practices increases student engagement and understanding with scientific content, rather than having students learn a series of factual content. The NGSS incorporates three-dimensional science learning. The SEPs teach students how to utilize the process of science to investigate phenomena while learning scientific content whereas the CCCs are overarching themes used in science and other disciplines. Intentionally using the SEPs and CCCs in science classrooms has the potential to increase student engagement in scientific practices and three-dimensional learning of science content.

CHAPTER THREE

METHODOLOGY

Demographics

To conduct my research focusing on intentionally incorporating the Science and Engineering Practices (SEPs) and Crosscutting Concepts (CCCs) from the Next Generation Science Standards (NGSS) into my classroom, I chose my 10th grade chemistry students. For the 2025-2026 school year, I had been assigned five sections of chemistry. The chemistry courses at Marshall High School (MHS) are leveled by student math placement and success in their ninth-grade biology course. I teach four sections of upper-level chemistry and one section of conceptual chemistry. The conceptual chemistry course moves at a slower pace, uses fewer mathematical concepts, and focuses on the essential standards for a general chemistry education. The upper-level chemistry courses are the more advanced sections of chemistry that move at a quicker pace, cover more depth and breadth of content, and are designed to prepare students for Advanced Placement chemistry and college science courses.

I chose my four sections of on-level chemistry for treatment because my conceptual chemistry class was not learning the same content as the upper-level course, and my data collection tools would have needed to be different in order to be used in conceptual chemistry. My conceptual chemistry course consisted of 27 students, which would have been a small sample to use for data collection. In addition, another teacher had two sections of conceptual chemistry, and we tried to follow the same content and use common assessments across our

classes. This has been the only year that I have taught all of the upper-level chemistry courses without a colleague to collaborate with and to prepare lab exercises alongside.

My upper-level chemistry courses consisted of 117 sophomores across four classes. Of these 117 students, parent consent was obtained from 79 of them. At MHS, students are in class for around an hour, five days a week, with slightly shorter classes on Tuesdays and Thursdays to make time for a built-in study hall period. My first hour chemistry class had 27 students, fourth hour had 31 students, fifth hour consisted of 29 students, and sixth hour had 30 students. These class sizes were larger this school year in comparison to the other 13 years I have taught at MHS as the recommended class size in my district is 26 pupils per teacher. A breakdown of each class's dynamics and demographics is shown in Table 1. The larger class sizes were manageable because of my students' attitudes and eagerness for learning.

Table 1. Demographic Data for Upper-Level Chemistry 2025-2026, ($N=117$).

	1 st Hour	4 th Hour	5 th Hour	6 th Hour
Male & Female	15 M, 14 F	11 M, 21 F	17 M, 13 F	19 M, 12 F
IEPs/504s	2 504	1 IEP, 0 504	0 IEP, 3 504	2 IEP, 3 504
Exchange Students	1 from Spain	None	None	2 from Spain 1 from Brazil

Treatment

Before treatment commenced in my chemistry classes, the research methodology for this project received an exemption by Montana State University's Institutional Review Board and compliance for work with human subjects was maintained (Appendix A). The treatment for my project occurred after unit 3 of our chemistry content and started with unit 4. At that point in the school year, my students had learned about the properties and changes of matter, the atom's structure, and the properties that each subatomic particle influences, and completed an in-depth

examination into an atom's nucleus including radioactivity and nuclear reactions. These units spanned from mid-August 2025 through mid-December 2025.

Before I began the treatment unit over the periodic table and trends, I started to collect data about student knowledge of scientific practices and how we had been using them in our class up until this point in the year. My students were given a Pre Survey: What does a Scientist do? (Appendix B). The goal of this survey was to gather data about my students' attitudes and perceptions about the process of science before specifically introducing the SEPs and CCCs of the Next Generation Science Standards. I followed up this open-ended qualitative survey with two different Likert surveys. The Knowledge of Science & Engineering Practices Likert Pre Survey focused on the SEPs, and the Knowledge of Crosscutting Concepts Likert Pre Survey focused on the CCCs (Appendix C and Appendix D). On each, the SEP and CCC were listed for students to identify their familiarity with the term. Upon the beginning of our second semester, I began to introduce to my students the SEPs and CCCs through a series of activities. First, students were given graphic organizers with all of them listed. Then, students participated in a series of station activities where they were asked to identify and match an SEP/CCC to a situation, and to explain how they have used SEPs and CCCs throughout the school year and on new situations as provided.

After introducing the SEPs and CCCs to my students and practicing them in a two-week mini-unit, I gave my students the Unit 4 Pretest—Periodic Table and Trends (Appendix E). This was used to gauge their prior knowledge of the periodic table as well as the SEPs and CCCs that they did a weeklong exploration of upon return from winter break in early January 2026. The pretest consisted of questions that covered content over the periodic table and content where

students had to identify the SEP and CCC used or explain what practices scientists used. Upon completion of the content covering the periodic table and trends, a Unit 4 Summative Test—Periodic Table and Trends was administered to all students (Appendix F). At the end of the unit, I gave students three surveys. The Post Survey: What does a Scientist do? used the same questions as the pre survey (Appendix G). Students were also given two new Likert surveys. The Knowledge of Science & Engineering Practices Likert Post Survey and the Knowledge of Crosscutting Concepts Likert Post Surveys had students rank their familiarity with each SEP and CCC after treatment (Appendix H, Appendix I). These surveys differed from the pretreatment surveys in that they asked students at the end to identify the SEP and CCC that they felt most confident and least confident using and why.

As I provided treatment and intentionally incorporated the SEPs and CCCs into learning, I kept a teacher journal to write down observations and notes about what I was hearing and seeing during my classes (Appendix J). I focused my notes on what went well and what needed improvement on when completing activities. I also used interview questions to ask students their opinions after participating in activities that used the SEPs and CCCs (Appendix K). I asked for volunteers and interviewed them during our advisory period. I recorded student responses in my teacher journal. All surveys were given utilizing Google forms and the pre and posttests were administered using Illuminate DNA software which is provided by the Calhoun County Intermediate School District (ISD).

Data Collection and Analysis Strategies

For data collection and analysis, a mixed methods approach was utilized. Quantitative data was collected using both pre and posttests over unit 4 the periodic table and trends.

Quantitative data was also gathered using Likert surveys both before and after treatment that focused on the SEPs and CCCs. These Likert surveys also collected qualitative data on the post surveys. The other qualitative data collected includes both a pre and posttreatment survey asking students what scientists do. Students were interviewed throughout the unit using a list of interview questions and teacher observations were recorded in a journal along with interview responses.

Data Collection Instruments: Pre-Treatment

To collect baseline data, three different instruments were utilized and given within two days of each other. The first instrument students completed was the Pre Survey: What does a scientist do? (Appendix B). This survey gauged student perceptions on the processes that scientists use, words they associate with science and scientific practices, and it asked students to describe activities we have already done in class that made them feel as if they were doing science. To analyze the results of this survey, themes were identified using thematic analysis as well as a frequency distribution of responses. The other two baseline data instruments I utilized gauged student knowledge of the SEPs and CCCs from the NGSS on the surveys entitled Knowledge of Science and Engineering Practices Pre Survey (Appendix C) and Knowledge of Crosscutting Concepts Pre Survey (Appendix D). On each, the SEP and CCC was listed for students to identify their familiarity with the term. Students had the opportunity to choose Not at all Familiar (1), Somewhat Familiar (2), Very Familiar (3) or Extremely Familiar (4). I provided examples for familiarity to help students determine as accurately as possible their awareness of each SEP and CCC. I analyzed these Likert surveys using mean and median, and ranked the SEPs and CCCs from least to most familiar to my students prior to treatment. I also generalized

these results for both pre and post treatment by calculating percent familiarity. I added together the responses for not at all familiar and somewhat familiar and compared to the responses for very familiar added with the responses to extremely familiar. I used the knowledge gained from these surveys to inform my instructional practices and unit planning.

At the start of the second half of the school year in January 2026, my students were first introduced to the SEPs and CCCs to kick off the second semester of school. After this mini unit where students learned what the SEPs and CCCs were and how to apply them to learning activities we have completed, students started their new unit on the periodic table and trends. Prior to starting content, students were given Unit Four: Periodic Table and Trends Pre Test (Appendix E).

Data Collection Instruments: Post-Treatment

The Unit Four: Periodic Table and Trends Post Test was administered upon completion of content standards (Appendix F). The pre and posttest were compared and analyzed for growth using normalized gains (Hake, 1998). The gain intervals were set at low gain being a difference between 0-.3. A medium gain was determined to be between .31-.69. A high gain was determined to be between .70-1. The gains were visualized on a bar graph showing the percentage of students who had high, medium, and low gains. The mean test averages were compared using a box and whisker plot.

Students were given the same three surveys post treatment to gauge their knowledge of the SEPS, CCCs, and attitudes about science. The Post Survey: What Does a Scientist Do? asked students what practices scientists engage with, what words they associate with science, and how their perspective and attitudes have changed after explicitly being taught the SEPs and CCCs

(Appendix G). Students also had a small Likert section on the post survey in which they were asked to what degree they agreed with four statements about the nature of science. The level of agreement was measured using the scaling of strongly disagree, disagree, agree, and strongly agree. The post survey results were compared to the pre survey using thematic analysis and frequency distribution to search for trends and to determine if the themes were broadened after treatment. Students were given the same Likert surveys about the SEPs and CCCs as before, but with a section for students to provide free response. The survey Knowledge of Scientific Practices Likert Survey Post asked students to choose their familiarity with each SEP on a scale of Not at all Familiar (1), Somewhat Familiar (2), Very Familiar (3) or Extremely Familiar (4) (Appendix H). The free response section of the survey asked students which SEP they felt most confident using and which SEP they felt least confident using and why. The survey Knowledge of Crosscutting Concepts Likert Survey Post was structured exactly like the SEP survey, with the exception of the CCCs being listed instead of the SEPs (Appendix I). Students also had a free response section on this survey post-treatment asking which CCCs they were most confident and least confident using. To get a general overview for both the SEPs and CCCs, I combined the categories not at all familiar and somewhat familiar to signify that students were unfamiliar and I combined very familiar and extremely familiar to signify that students were familiar with the SEP or CCC. I analyzed the free response questions for similar themes using thematic analysis and percent confidence with ranking the SEPs and CCCs from the least to most familiar to my students. I compared the results of percent familiarity both pre and posttreatment.

As students worked through their periodic table unit, I collected notes in a Teacher Observations Journal (Appendix J). My entries were analyzed for strengths of activities,

weaknesses of activities, and reflection based on what I heard my students say. I used these entries as a frame of reference around the results of my surveys and test data collected. I also conducted student interviews as we worked with the SEPs and CCCs using questions from the List of Student Interview Questions (Appendix K). Students were chosen at random, and permission was granted or denied by the student. I used these interview questions to gauge student thoughts about science, what they perceive the work of scientists to entail, what they remembered from science courses prior to their sophomore year, and to see if they felt like they were doing science in science class. All the data collection sources used to answer the focus question are triangulated in Table 2.

Table 2. Data Triangulation Matrix

Focus Question	Data Source #1	Data Source #2	Data Source #3	Data Source #4	Data Source #5
How will purposefully teaching the Science and Engineering Practices and Crosscutting Concepts of the Next Generation Science Standards impact student achievement and perceptions in a high school chemistry course?	Pre and Post tests over unit four which covers content learned about the periodic table and its trends, patterns, and element behavior titled “The periodic table and trends.”	Likert surveys both pre- and post-treatment to gauge student knowledge of the SEPs and CCCs. Knowledge of SEPs Pre and Post Likert Survey. Knowledge of CCCs Pre and Post Likert Survey.	Open-ended survey “What does a Scientist Do?” to ask students their opinions and views on science both before and after treatment.	Teacher generated journal of observations as students work through activities in the unit that incorporate the SEPs and CCCs intentionally into the curriculum.	Student interview questions and responses after activities that focus on the incorporation of an SEP/CCC with specific chemistry content.

CHAPTER FOUR

DATA ANALYSIS: CLAIMS AND EVIDENCE

Results

The data collected in order to answer the question, How will purposefully teaching the Science and Engineering Practices and Crosscutting Concepts of the Next Generation Science Standards (NGSS) impact student achievement and perceptions/attitudes in a high school chemistry course? was collected over a five-week period over a chemistry unit covering the periodic table and trends. The data consisted of six different surveys, a pre and post content summative assessment, student interviews, and teacher notes. Upon completion of this study, the results showed that students grew in familiarity and confidence in using the science and engineering practices (SEPs) and crosscutting concepts (CCCs) of the NGSS. Another finding was that students could describe in more detail what a scientist does while relating to the SEPs and CCCs. Lastly, students showed growth in content knowledge and their knowledge of the SEPs and CCCs throughout a unit over the periodic table and trends. The results of each data instrument are described in the following sections to support the aforementioned claims.

What Does a Scientist Do?

The results of the pre survey What Does a Scientist Do Pre? ($n=62$) (Appendix B) showed knowledge of the science and engineering practices (SEPs) without explicitly using the terminology (Figure 1). Student responses were devoid of the crosscutting concepts (CCCs) in the pre survey data. Before treatment, students identified the following main themes in their responses when asked what they perceived the work of a scientist to be: analyzing data,

labs/experiments, research, claims, evidence, reasoning (CERs), hypotheses, math, solving problems/answering questions/forming conclusions, and making observations. Post treatment, on the survey What Does a Scientist Do Post? ($n=62$) (Appendix G) these same themes persisted with new additions such as looking for patterns, communicating information, building models, and the SEPs/CCCs were mentioned explicitly. Students were also asked to identify on both the pre-and-post treatment surveys words they associate with science.

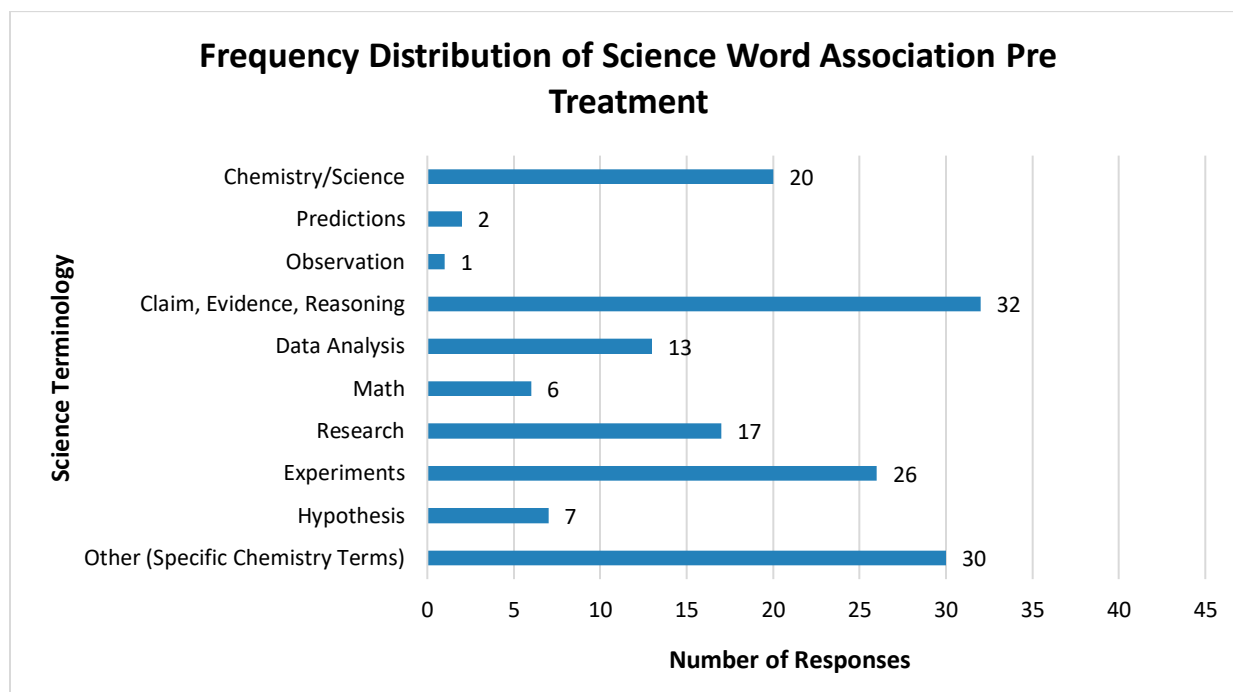


Figure 1. Frequency distribution of science word association pretreatment, ($n=62$).

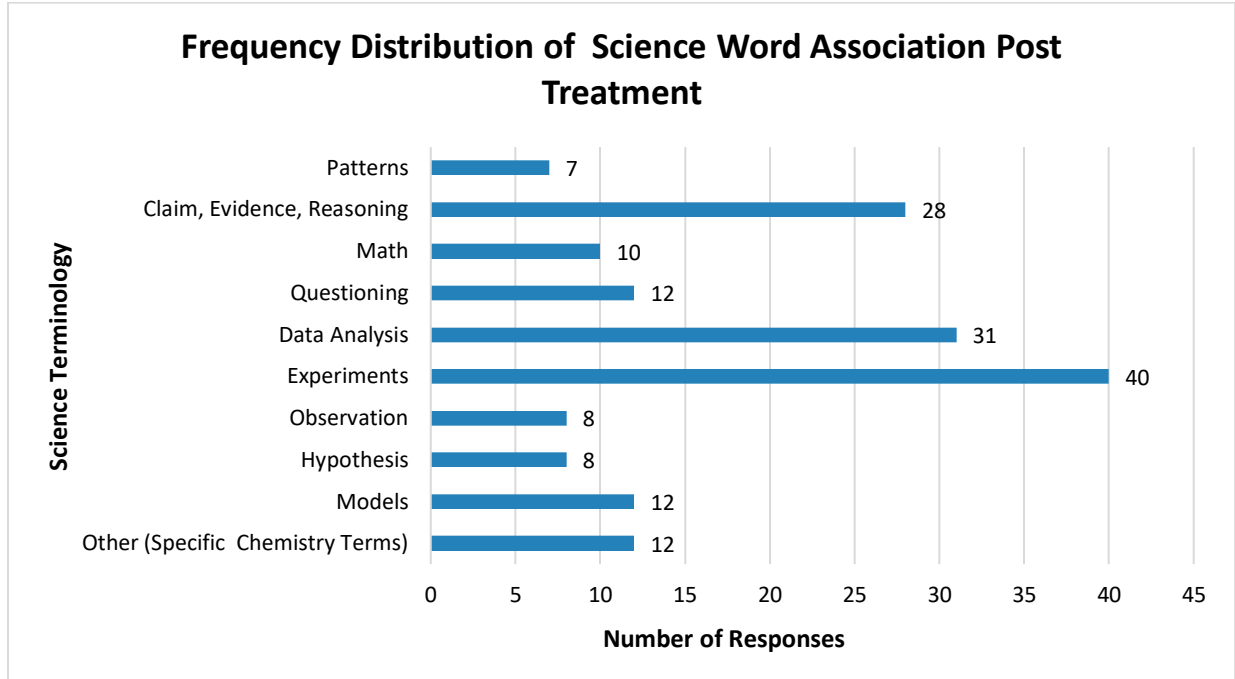


Figure 2. Frequency distribution of science word association post treatment, ($n=62$).

The frequency distribution from pre to post treatment shows the same word associations such as claim, evidence, reasoning, math, experiments, observations, data analysis, and hypothesis (Figures 1 & 2). There were a few different terms that showed up post treatment including patterns, models, and questioning which are some of the CCCs and SEPs. Patterns is a crosscutting concept whereas asking questions and developing models are science and engineering practices. In both pre and post treatment word associations, experiments and claim, evidence, reasoning were two of the top responses with 32 versus 28 respondents (51% versus 45%) listing CER and 26 versus 40 respondents (42% versus 65%) listing labs/experiments as words that students associate with scientific work. Thirty-one percent of respondents listed that math and data analysis were words that they associated with science pretreatment while 66% of respondents listed math and data analysis as words associated with science post treatment. In each thematic analysis, I listed another category to represent phrases or terms that students

mentioned specific to the chemistry content that we had covered in class. For example, many students wrote terms such as atoms, protons, neutrons, electrons, flame test, candy lab, or nuclear, for their responses. Whereas these were excellent recalls of material we had learned, they were very specific examples of scientific content. A vocabulary term that was only listed by students once pretreatment and eight times post treatment was the term observation. In almost all laboratory exercises students participated in, they were required to make observations.

Student interviews supported the data collected on the pre and post surveys What Does a Scientist Do?. Of 11 students interviewed, all responded with a yes when asked if they could describe to a friend what a scientist does. A student summed up scientific work succinctly by saying that they do the SEPs and CCCs. Another student went into extreme detail with examples by describing scientific work as “They mainly, have an issue, something to discover, do certain tests to identify and describe (like the periodic table thing/meteor question on the test). They go into the microstate and figure out structure/function.” This student proceeded to use the flu shot as an example of scientific work “Flu shot example, look at the molecular level to find out a cure.” One student said that they do the scientific method to explain the world whereas another student elaborated on the scientific method and stated that “a scientist is a person who studies and obtains data from different tests from chemicals in labs and uses it to create something/draw a conclusion about information that they obtain.” No students mentioned the scientific method on either the pre or post survey, but all of them described pieces of it in their interview responses. Of the 11 students interviewed, five students mentioned labs, conducting experiments, or hands on research. This matches the post survey data’s high response frequency of experiments in science word association.

Lastly, on the survey What Does a Scientist Do Post? students were given four statements, and they had to identify to which degree they agreed with each. Fifty-eight students (94%) agreed that they can relate the SEPs and CCCs to what we have done in class. Fifty-four students (87%) agreed that they can describe the scientific practices used to construct the periodic table. Lastly, 56 students (90%) agreed that they could describe what a scientist does in their daily work. Fewer students were as confident when asked to differentiate between an SEP and CCC on the survey's second question. Only 11 students (18%) strongly agreed that they could whereas 20 or more students (32%) strongly agreed with the other three statements. In general, between 83% and 94% of all students had a degree of agreement with the statements on this post Likert survey (Figure 3).

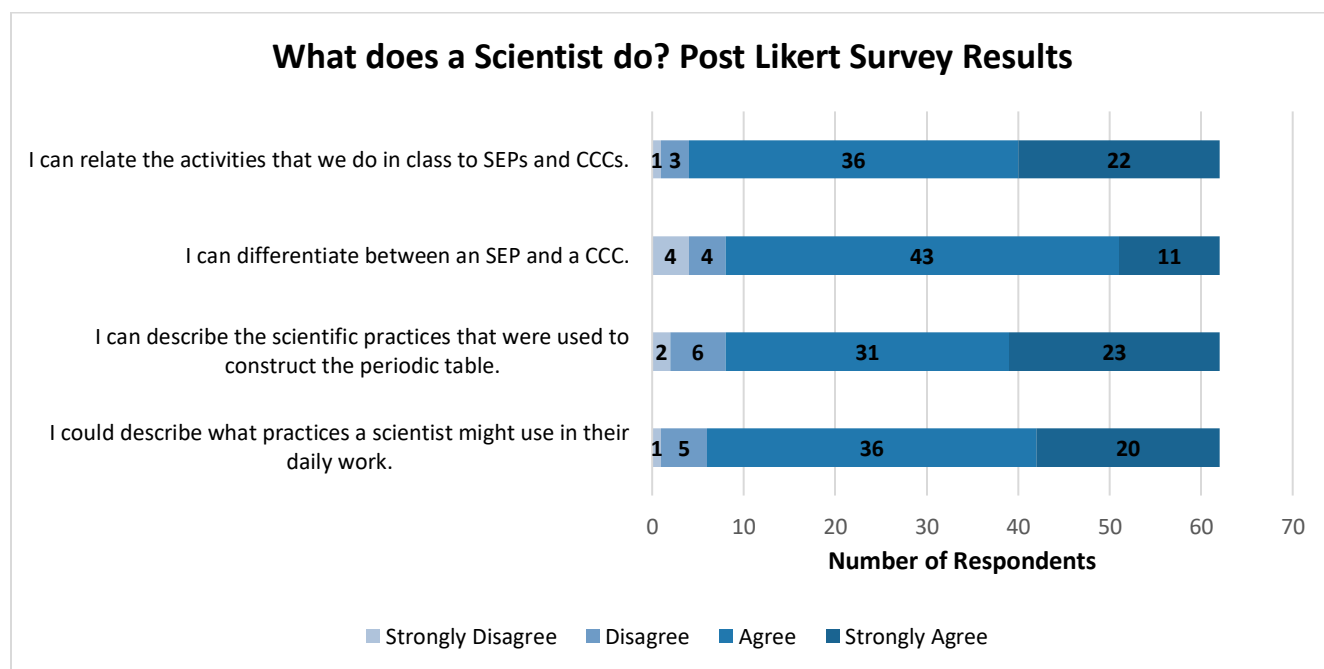


Figure 3. What does a scientist do? Post Likert survey results, ($n=62$).

Knowledge of Science and Engineering Practices Likert Surveys

To gauge student knowledge of the science and engineering practices (SEPs) before treatment, students were given the Likert survey Knowledge of Science and Engineering Practices Pre Survey ($N=79$) (Appendix C). On this survey, students reported that they were least familiar with the SEP obtaining, evaluating, and communicating information. Overall, 58% of students listed this SEP as being not at all familiar or somewhat familiar. The other SEPs that students rated as having little familiarity with were planning and carrying out investigations (55%) and constructing explanations (53%). The SEP that students were most familiar with before treatment was analyzing and interpreting data. Sixty-three percent of students named this SEP as the one that they were most familiar with overall. The other SEPs that students rated as being familiar with were using math and computational thinking (52%) and asking questions (54%) (Figure 4).

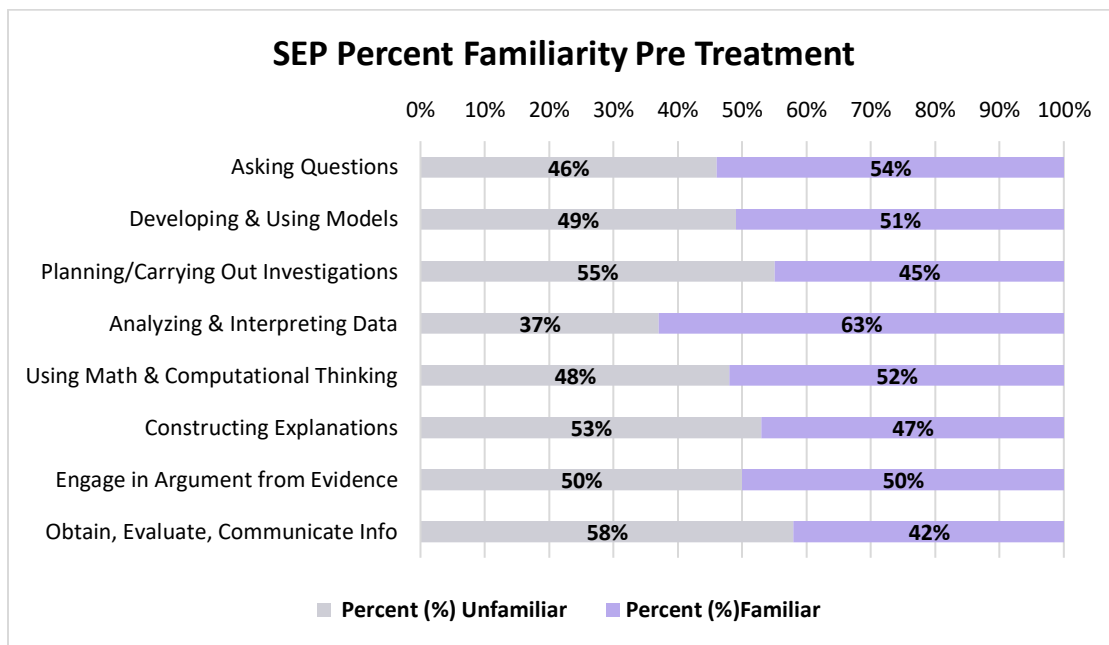


Figure 4. SEP percent familiarity pretreatment, ($N=79$).

Post treatment data for the Likert survey Knowledge of Science and Engineering Practices Post Survey ($n=60$) shows tremendous growth in familiarity for all eight SEPs (Appendix H). Ninety percent of students identified the SEPs developing and using models, analyzing and interpreting data, and engaging in argument from evidence as the SEPs that they were most familiar with (either very or extremely familiar) on the Likert scale rating. The SEPs students identified as least familiar were using math and computational thinking (77%) and constructing explanations (79%). Overall, compared to the pre survey, students went from the highest familiarity with any SEP being at 63% to the lowest familiarity on the post survey of 76%.

From pre to post treatment, all SEPs showed growth in familiarity. The SEP asking questions grew from 54% familiarity to 92% familiarity, developing and using models grew from 51% to 90% familiarity, planning and carrying out investigations grew from 45% to 85% familiarity, analyzing and interpreting data grew from 63% to 90%, using math and computational thinking grew from 52% to 77%, constructing explanations grew from 47% to 78%, engaging in argument from evidence grew from 50% to 90%, and obtaining, evaluating, and communicating information grew from 42% to 87% familiarity (Figure 5).

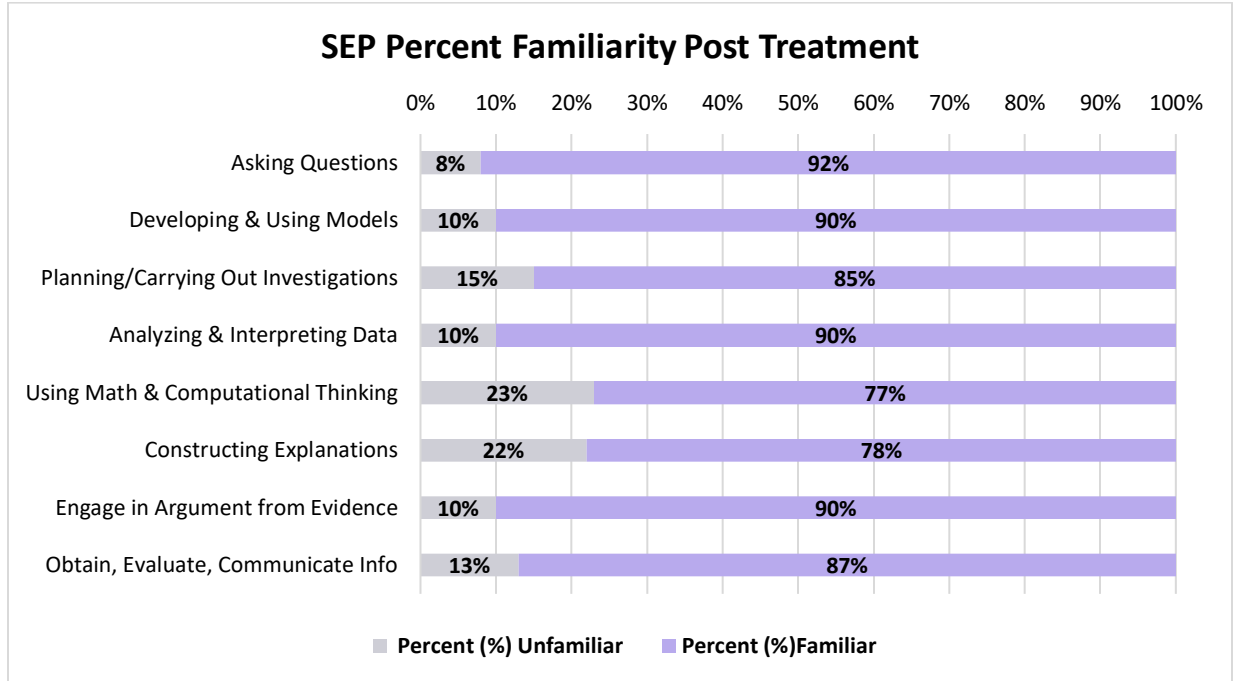


Figure 5. SEP percent familiarity post treatment, ($n=60$).

So far, I have summarized the data and grouped together the parameters of the Likert scale for simplicity. In addition to this combined data, I have separated the Likert ratings for both the pre and post SEP Likert surveys in Figure 6. On both the pre and post surveys, students had the same options of not at all familiar, somewhat familiar, very familiar, and extremely familiar.

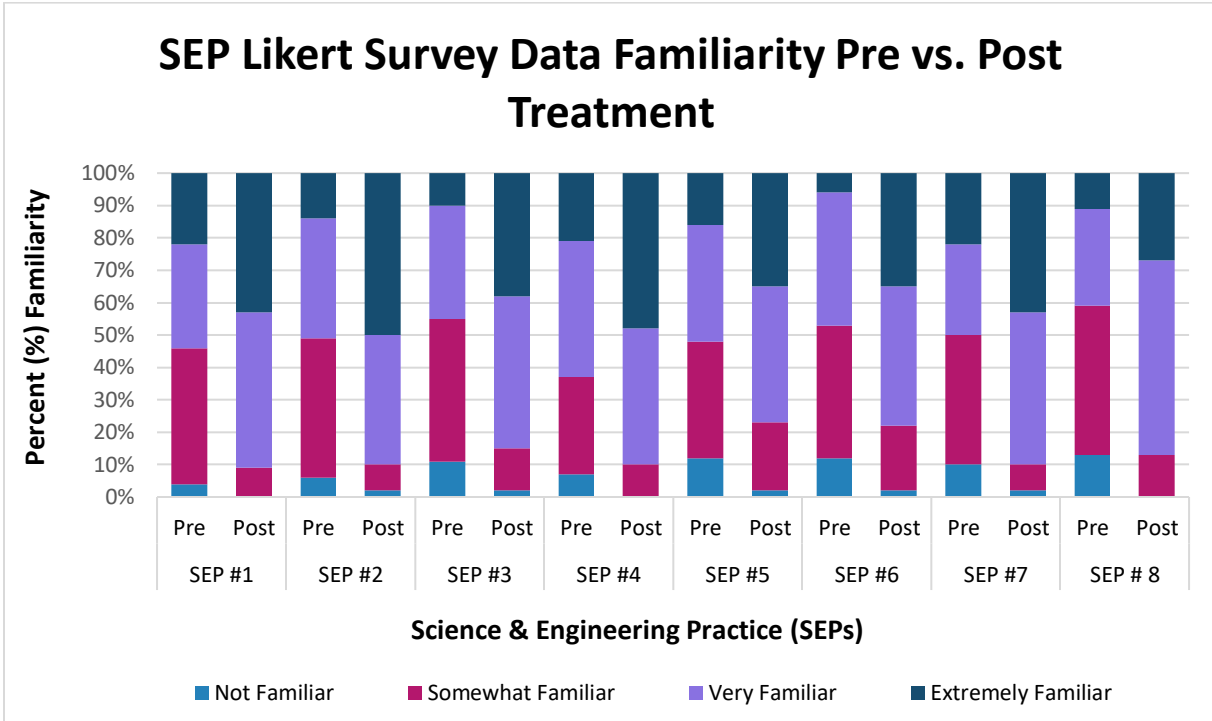


Figure 6. SEP familiarity Likert survey data pre vs. post treatment. SEP #1 represents asking questions, SEP #2 represents developing and using models, SEP #3 represents planning and carrying out investigations, SEP #4 represents analyzing and interpreting data, SEP #5 represents using math and computational thinking, SEP #6 represents constructing explanations, SEP #7 represents engaging in argument from evidence, SEP #8 represents obtaining, evaluating, and communicating information, ($N=79$ pre and $n=60$ post).

Students identified the SEPs of asking questions (SEP #1), analyzing and interpreting data (SEP #4), and obtaining, evaluating, and communicating information (SEP #8) as being somewhat familiar with no students selecting not at all familiar post treatment (Figure 6). For all other SEPs, only one student said that they were not at all familiar with them, indicating that this may have been an outlier in the data. From pre to post treatment, students showed 36% growth in familiarity with SEP #2 developing and using models. The student responses of extremely familiar doubled for each SEP during treatment. Students had a mixed familiarity with SEP #6, constructing explanations. This SEP grew from 6% extreme familiarity to 35% extreme familiarity which equates to almost six times growth after treatment. However, constructing

explanations was still one of the SEPs that had the largest number of students reporting it as being somewhat familiar after treatment (20%). Students stated that they found it challenging to put their thoughts into writing and that they found this SEP confusing and that they tend to overthink when writing. Twenty-two percent of students also identified SEP #5, using math and computational thinking, with the largest amount of somewhat familiarity.

Student interviews supported the findings post treatment. When asked, nine of 11 interviewees answered that they felt confident describing what the SEPs were. Two students said that they were mostly or kind of confident. Three students reported that the SEPs were easier to understand after we had learned what they were in class. Another student stated that having a list of them available on their Unit 4 Periodic Table and Trends summative assessment made it easier to discuss them when asked. As part of the interviews, students were asked which SEPs they thought we had used most often in class. After performing a thematic analysis, four students identified that we had used all SEPs in some way or form throughout our school year. The next frequent SEPs to be mentioned were developing and using models (10 students), asking questions and defining problems (six students), and planning and carrying out investigations (five students). One student pointed out that that they had not had the opportunity to plan many lab investigations but had participated often in teacher-led labs. The SEP mentioned in interviews the least was constructing explanations. This matches the data from Figures 5 and 6 respectively in which only 78% of students were familiar with this SEP and of those 78%, only 35% ranked it as extremely familiar.

Lastly, students were asked to identify which SEP that they felt the most confident using and least confident using and to provide reasoning for their choice. The results of these questions are summarized in Figure 7 below.

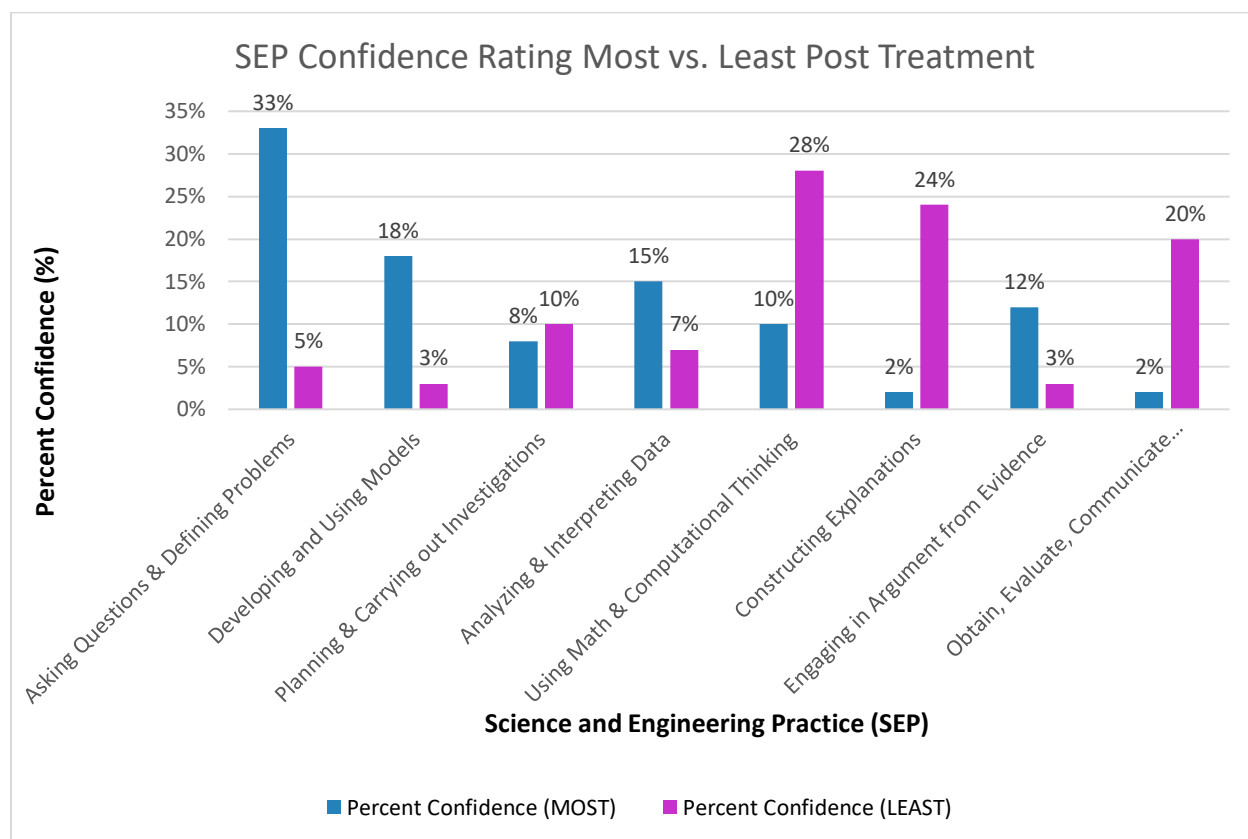


Figure 7. SEP confidence rating most vs. least post treatment, ($n=60$).

Students identified that they were most confident (33%) with asking questions and defining problems followed by developing and using modes (18%). Students stated that they selected asking questions because they are asked questions all the time in life. At least 10 students stated that this was the easiest SEP. Students were confident in developing and using models because “we used them a lot in class since the periodic table is a model” and “we made one after a lab investigation in class.” Students were least confident with using math and

computational thinking (28%) and constructing explanations (24%). One student mentioned that their reasoning for choosing math and computational thinking was that “we haven’t done much of that.” Six students (10%) reported that they disliked math or that math was hard for them. For constructing explanations, students stated that it is difficult to put their thoughts onto paper and that it is hard to get people to understand their thoughts. One student pointed out that they were not directly taught how to construct an explanation.

As for the other four SEPs, students mentioned that they did not rank planning and carrying out investigations with confidence because they had not had the opportunity to plan their own lab but had participated in many. Other students mentioned that they feel most engaged in science when doing labs. Some students chose analyzing and interpreting data as their most confident area because we use it often in class and some students reported that they are really good with numbers and like using data for evidence. The least confident students with this SEP mentioned that they are not good with math or may flip numbers when looking at data. Thirteen percent of students mentioned that they were confident in engaging in argument from evidence because we have done so many CERs in class. The 3% of students who did not feel confident with this SEP said that CERs were complicated and opinion based. I took this to be an outlier based on a misconception in the data as by definition, when you have an argument from evidence, it is not opinion based but rooted in facts and data. Lastly, only 2% of students felt confident with obtaining, evaluating, and communicating information and 20% felt least confident with this SEP. The student who felt confident simply stated “it comes easy to me” while the least confident students said that they were confused by this SEP, did not practice it enough, and that they were not good communicators.

Knowledge of Crosscutting Concepts Likert Surveys

To gauge student knowledge of the crosscutting concepts (CCCs) before treatment, students were given the Likert survey Knowledge of Crosscutting Concepts Pre Survey ($n=68$) (Appendix D). Before treatment, students named the CCCs of patterns (76%) and cause and effect (75%) as most familiar to them. In student interviews, the sentiment with these two crosscutting concepts was that they were easier because the students do them in other classes. One student stated, “we use this in AP World History all of the time.” The crosscutting concepts of scale, proportion, quantity and systems and system models were identified as the crosscutting concepts that were least familiar to students pretreatment. Seventy-five percent of students reported that they were unfamiliar with scale, proportion, and quantity whereas 68% of students reported that they were unfamiliar with systems and system models (Figure 8). While doing our station activities over the crosscutting concepts, I recorded in my teacher journal that many students were confused as to what scale, proportion, and quantity meant. After treatment, students were given a similar Likert survey entitled Knowledge of Crosscutting Concepts Post Survey ($n=69$) (Appendix I). On this survey, students again ranked their familiarity with each crosscutting concept, and they were also asked some open-ended questions about their confidence with using CCCs (Figure 9).

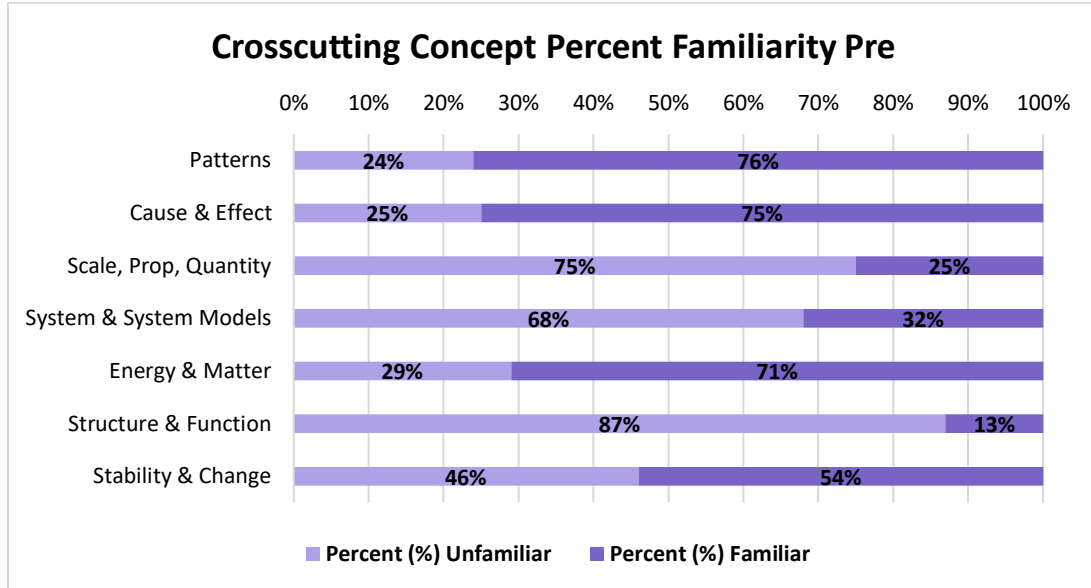


Figure 8. CCC percent familiarity pretreatment, ($n=68$).

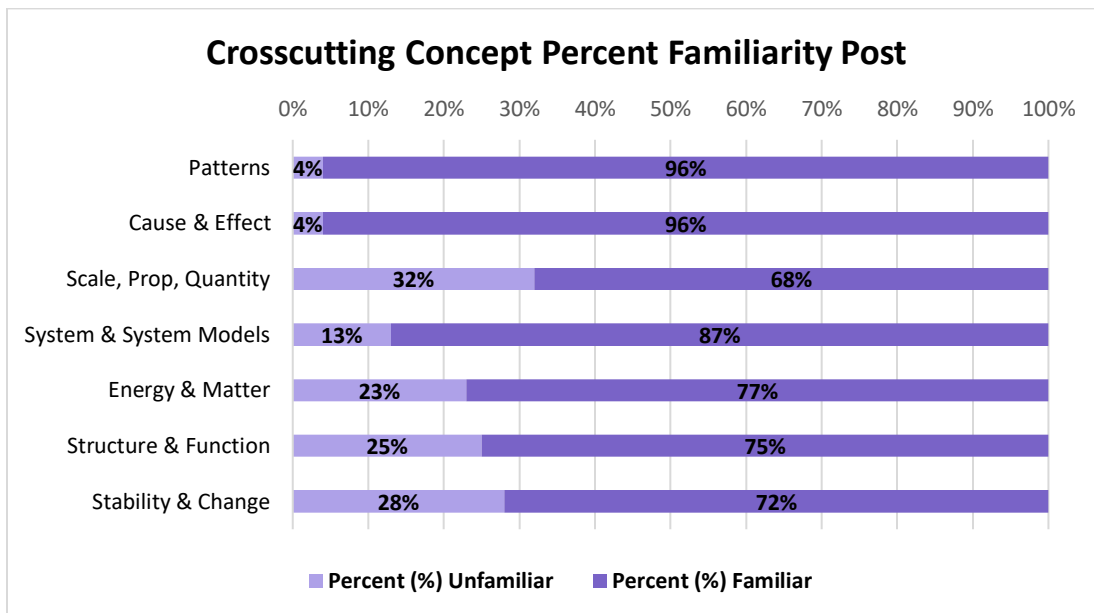


Figure 9. CCC percent familiarity post treatment, ($n=69$).

After treatment, each crosscutting concept showed growth in familiarity across all categories. Students named the CCCs of patterns (96%) and cause and effect (96%) as the ones that were most familiar to them. Each category grew by around 20% from pre-to-post treatment.

The CCC that was still least familiar to students was scale, proportion, and quantity. Only 68% of students were familiar with this CCC and 32% still ranked it as unfamiliar. However, the unfamiliarity decreased from 68% pretreatment to 32% post treatment. Pretreatment, system and system models was identified as one of the CCCs that was most unfamiliar (68%) to students. Post treatment, only 13% of students stated that they were still unfamiliar with this CCC and 87% said that they were familiar with it (Figure 10). On both the pre and post surveys, students had the same options of not at all familiar, somewhat familiar, very familiar, and extremely familiar.

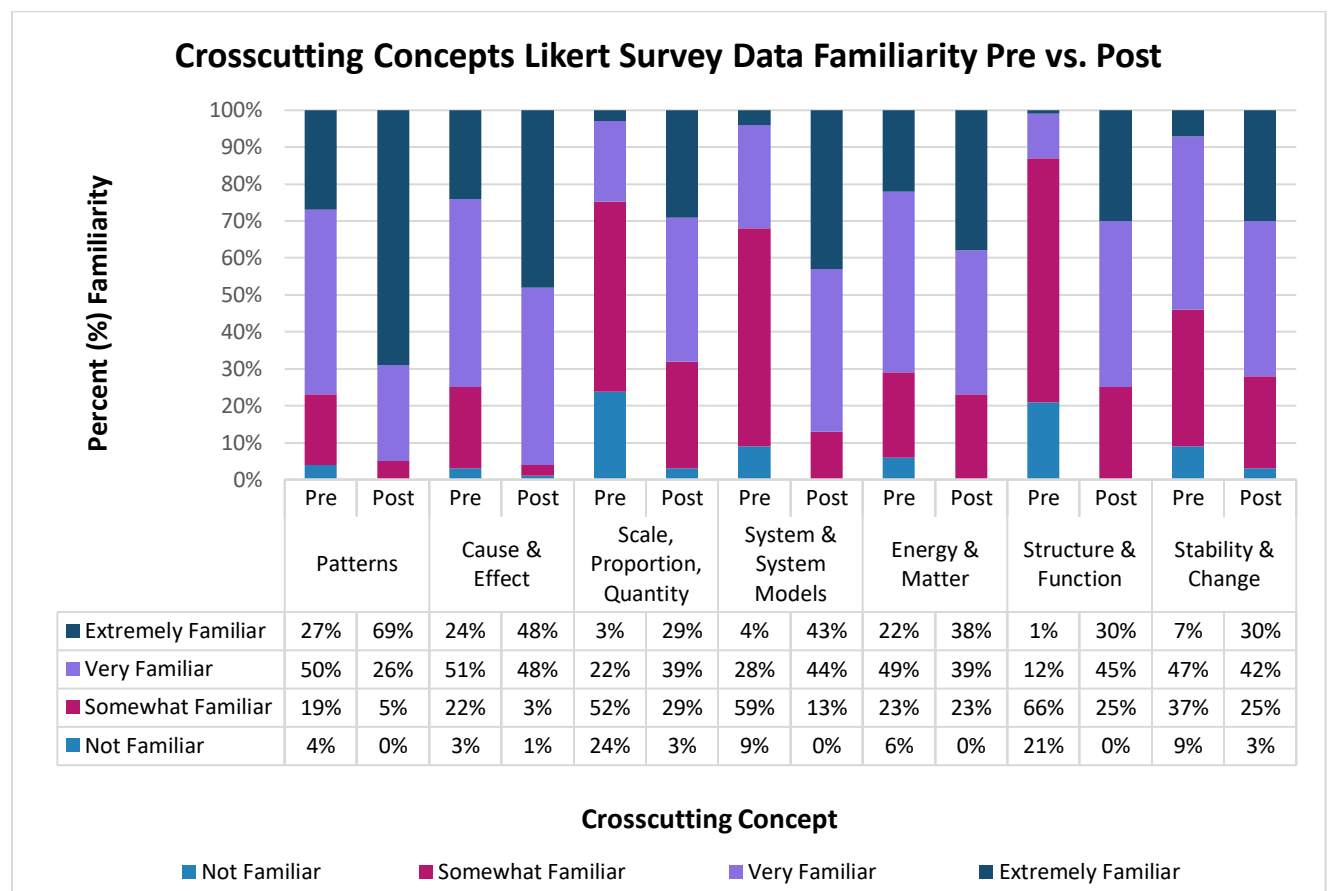


Figure 10. CCC Likert survey combined data pre vs post treatment, ($n=68$ and $n=69$).

The two crosscutting concepts pretreatment that were ranked as extremely familiar were patterns (27%) and cause and effect (24%). After treatment, the percentage of extreme familiarity grew to 69% for patterns and 48% for cause and effect. The CCC that was least familiar (not at all) on the pretreatment survey was scale, proportion, and quantity. Twenty-four percent of students chose this CCC as being not at all familiar before treatment. After treatment, 3% of students chose this CCC as not at all familiar. In addition, patterns, system and system models, and energy and matter all had 0% percent of students select that these were not at all familiar post treatment. The crosscutting concepts that students identified on their post surveys as needing more practice with were energy and matter, scale, proportion, quantity, structure and function, and system and system models. Students mentioned in their exit surveys that energy and matter was something that we never covered in this unit and was something that they did not quite know how to explain. In regard to scale, proportion, and quantity, students stated that we did not practice it in the unit and that calculating is difficult for them. One student stated directly in their interview that “we did not use scale, proportion, and quantity a lot.” The same sentiment was echoed in regard to structure and function and system and system and system models. Students reported on the post survey that we did not practice these much in class during the treatment unit.

Post treatment, students were asked about their feelings of confidence using the crosscutting concepts in class. Sixty-five percent of students stated that they were confident with using patterns post treatment. Since our treatment unit focused on the periodic table, students stated that we learned a lot about patterns with the periodic table and that we use these every day in life. Only one student reported that they never think about patterns or sequences in everyday

life. Twenty percent of students reported that they were most confident using cause and effect. Students stated that they use cause and effect all of the time in their AP World History course and that we have used cause and effect when writing CERs (claim, evidence, reasoning) this year in chemistry. The CCC that students felt least confident using post treatment was scale, proportion, and quantity (41%). Students stated that math is hard, and we do not use it daily in class. No students selected the CCC of stability and change as being confident with or not confident with (Figure 11).

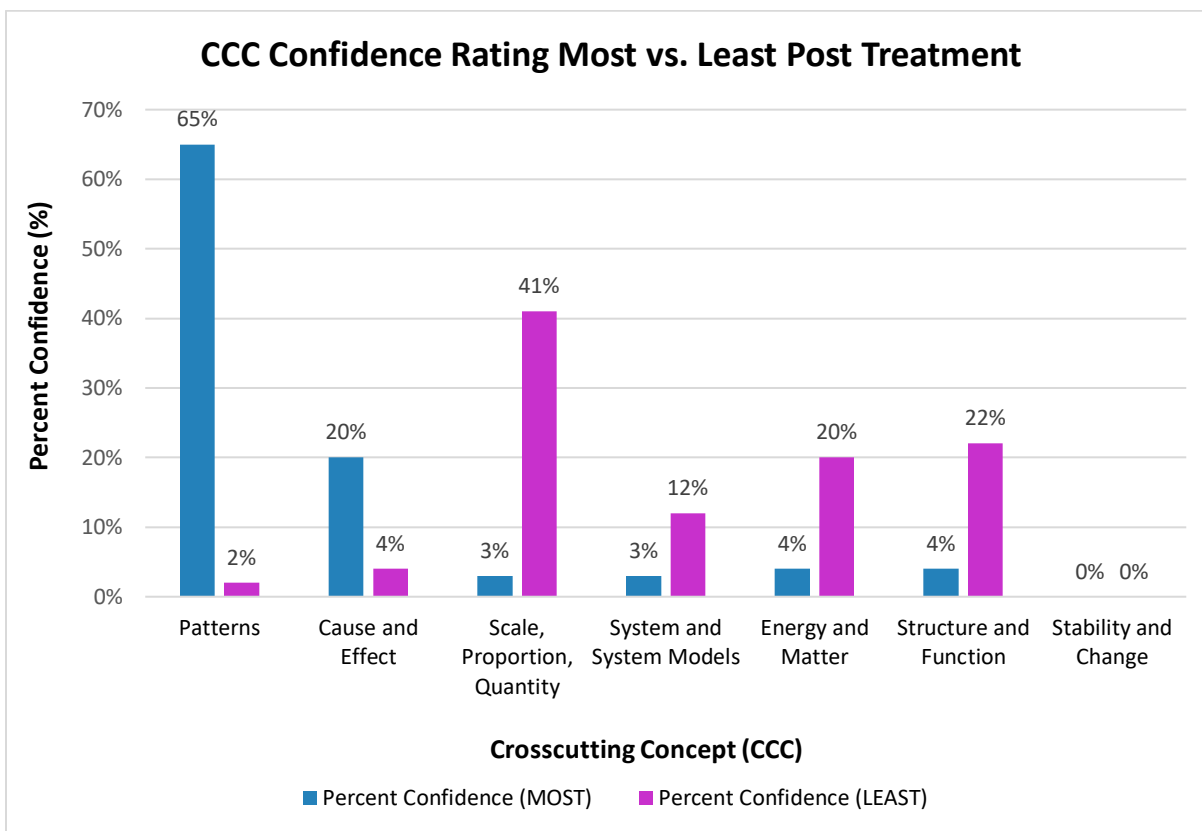


Figure 11. CCC confidence rating most vs. least post treatment, ($n=69$).

The Periodic Table and Trends Pre and Post Test

To measure student growth in their knowledge of the SEPs and CCCs along with the content over the periodic table and trends, a pre and posttest was administered. The Unit Four Pretest: Periodic Table and Trends had a mean score of 38% ($N=79$) (Appendix E). The posttest Unit Four Test: Periodic Table and Trends had a mean score of 85% ($N=79$) (Appendix F). On the pretest, one student scored 0% whereas on the posttest, four students scored 100%. The lowest score on the posttest matches up with the median of the 3rd quartile on the pretest which was 50% (Figure 12).

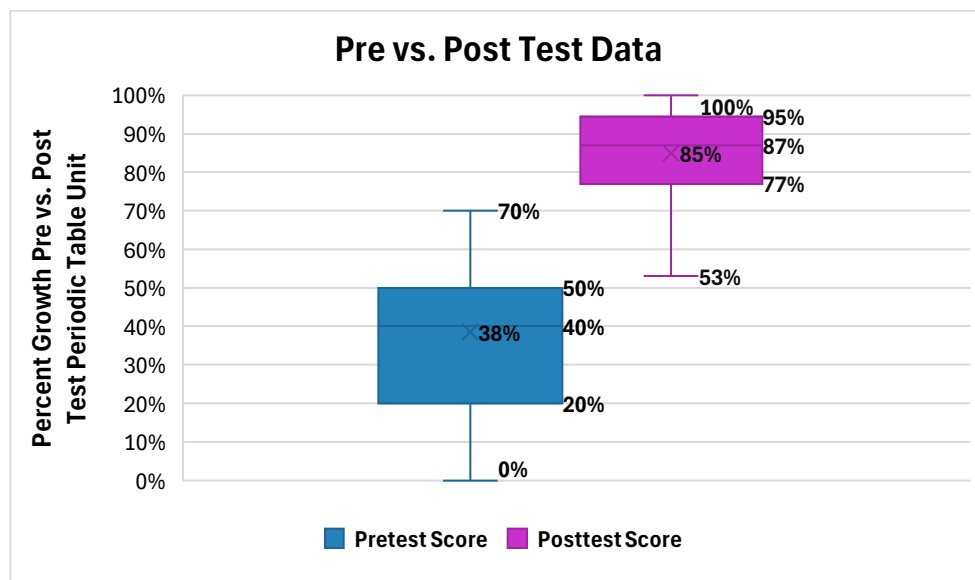


Figure 12. Box and whisker plot showing pre vs. posttest data for the periodic table and trends summative assessments, ($N=79$).

The pre and posttest were analyzed for growth using normalized gains (Hake, 1998). The gain intervals were set at low gain being a difference between 0-.3. A medium gain was determined to be between .31-.69. A high gain was determined to be between .7-1. Six percent of

students had low gains, 23% of students had medium gains, and 71% of students had high gains (Figure 13).

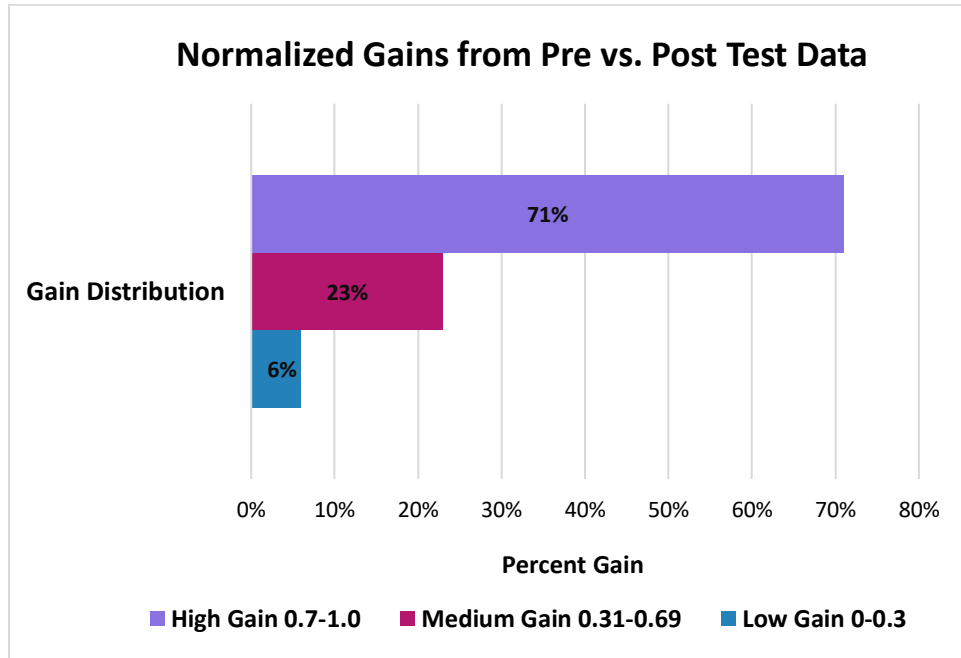


Figure 13. Normalized gains from pre vs. posttest data, ($N=79$).

CHAPTER FIVE

VALUE: REASONING AND REFLECTION

Claims from the Study

This study measured the effects of intentionally teaching and practicing the science and engineering practices (SEPs) and crosscutting concepts (CCCs) of the Next Generation Science Standards (NGSS) on student achievement and perceptions/attitudes about science in a high school chemistry course. This study showed that all students grew in their content knowledge of the periodic table and trends. These higher scores were linked to student confidence and familiarity with the SEPs and CCCs, and the ability to identify them from pre-to-post treatment. Lastly, student attitudes about what a scientist does in their daily work did not shift greatly from pre-to-post treatment, but students were able to relate more of the SEPs and CCCs with scientific work. In this chapter, I will discuss the findings from this study and implications for further consideration.

Effects on Student Achievement

All students showed growth in their content knowledge and knowledge of the SEPs and CCCs from pre to post treatment. A pre and posttest was used to analyze growth during this study. The mean average score increased by 47% from pre to post test. The lowest score increased by 53%, and the highest score by 30%. The pre and posttest included questions that required students to have content knowledge about the periodic table and trends, to identify specific SEPs and CCCs, and to use these practices to answer content questions. Comparatively, using Hake's (1998) normalized gains statistical test, 94% of students showed medium to high

gains, leading me to conclude that student achievement grew due to the instructional practices and classroom activities that students partook in during the treatment unit. During the unit, an overarching theme from a lab activity was utilized where students tested and grouped eight fictitious elements into their own models of periodic tables. Students produced these tables after analyzing their lab data for similar patterns and trends. Students then communicated their findings with a claim, evidence, reasoning summary of their model periodic tables. As more content was taught, this anchoring activity was referred to throughout the treatment. Students were asked to identify SEPs and CCCs that they used in their work as practice throughout so that they were best prepared for the summative unit assessment. These classroom activities helped students to grow and learn throughout the treatment unit in order to demonstrate their knowledge on the posttest. I must say that these results did not surprise me as my students typically performed better on posttests than on pretests. However, I was impressed that my students could easily identify and reason what SEPs and CCCs were used in a scenario and could demonstrate knowledge of these skills on questions throughout the unit and posttest.

Effects on Student Science Attitudes and Perceptions

Familiarity of SEPs and CCCs. When students have the opportunity to practice skills, it helps them grow in their familiarity and confidence. All students grew familiar with both the SEPs and CCCs from pre-to-post treatment. Both pre and post treatment, students identified the SEPs of analyzing and interpreting data and asking questions as being most familiar. Developing and using models and engaging in argument from evidence were the other SEPs that became most familiar. These four SEPs were the ones we practiced the most throughout the treatment unit. These practices, by design, are interconnected and best used as active engagement tools for

students exploring the process of science (National Research Council, 2012). Both pre and post treatment, students identified that patterns and cause and effect were the CCCs most familiar to them. Pretreatment, 76% of students ranked patterns as being familiar and 75% of students ranked cause and effect as being familiar. There was no major shift in which CCCs students felt most familiar with, but the percentage of students that were familiar with these grew after treatment. Students stated in interviews and Likert surveys that we used patterns all the time in class and that they used cause and effect in other courses such as their AP World History and Honors English courses. The purpose of the crosscutting concepts is to link together the science and engineering practices and content knowledge across science disciplines (Fick, 2016). I am pleased that some branch outside the science classroom into other courses and that my students could identify them elsewhere.

The SEPs and CCCs that we did not practice often throughout treatment were the ones that students ranked as least familiar. The SEPs of using math and computational thinking as well as constructing explanations were mentioned as least familiar but did grow in familiarity throughout treatment overall. The CCC of scale, proportion, and quantity was ranked lowest in familiarity throughout the data collection of this research. Based on student interview data and Likert surveys, I think this is because they did not do math throughout this unit other than looking at atomic radius, ionization energy, and electronegativity values which students analyzed the trends for. If I were to give my students a survey after doing our quantifying matter unit and stoichiometry, I would expect different responses from my Likert surveys in regard to this CCC.

The SEPs and CCCs that students were most familiar with prior to treatment did not shift significantly after treatment. The SEPs students were most familiar with both pretreatment and

post treatment were analyzing and interpreting data as well as asking questions. As I mentioned above, the CCCs that students were most familiar with prior to and after treatment were the same—patterns and cause and effect. I think that depending on the content being covered, students would select different SEPs and CCCs as being most familiar. I do not think that the most familiar SEPs and CCCs are set in stone. Since this unit was all about the periodic table as a model to describe elements, it is only natural that students would look at the patterns on the table and identify the trends.

Confidence of SEPs and CCCs. As part of this study, students ranked the SEPs and CCCs according to familiarity as discussed above, and they also ranked the SEPs and CCCs based on how confident they felt using them and identifying them. For the most part, the level of confidence corresponded with their familiarity with an SEP or CCC. Thirty-three percent of students rated asking questions as what they were most confident with and 92% said this SEP was most familiar to them. Students still felt the least confident with using math and computational thinking. Most students who chose this SEP stated that they were not fans of math or struggled with math. An exception to this correspondence was that only 15% of students said that they were most confident with the SEP analyzing and interpreting data whereas 90% had said they were familiar with this SEP. It seems that awareness of something and the confidence to perform it are two totally separate entities. As for the CCCs, 65% of students were confident with identifying patterns which corresponds with the 96% of students that said they were most familiar with patterns. The CCC that students were least confident with was scale, proportion, and quantity. Forty-one percent of students stated they were least confident with this CCC. It appears that we need to practice math skills more often in my classroom. I find it odd that my

students identified the one math SEP and CCC as their least confident. This was our fourth unit of the year, and students had used math in unit two and unit three prior to this treatment.

Scientific Work. All students were somewhat aware of what a scientist does pretreatment, and these attitudes shifted slightly but not drastically after treatment. Pretreatment, most students stated that scientists do experiments, analyze data, and use claim, evidence, reasoning when asked what scientists do. Post treatment, students still responded with these same practices as what scientists do, but they also gave more specific examples from things we did throughout the year in class (such as specific content covered or lab experiments). Post treatment, students added specific SEPs and CCCs to their responses when describing what a scientist does such as models, questioning, and hypotheses. Students were also given a series of statements asking them to share their agreement. Post treatment, 90% of students agreed that they could describe what a scientist does. Eighty-seven percent of students said that they could identify the SEPs and CCCs used to construct the periodic table which agrees with their posttest summative assessment scores. Eighty-seven percent of students said they could differentiate between an SEP and a CCC, and 94% of students said they could relate classroom activities to the SEPs and CCCs. My students are aware that scientists do more than just experiments, but they still listed that SEP more than anything else as the thing that scientists do the most, although doing an experiment is just one of eight SEPs. Pretreatment, my students had never heard of the term SEP or CCC because they had never been explicitly taught them. I am happy to see that they were made aware of all of the components and pieces of science throughout treatment.

Value of the Study and Consideration for Future Research

The NGSS were designed to make learning science a more immersive experience than simply learning content and reciting facts. By incorporating all three dimensions of the NGSS, students can achieve a broader understanding of scientific processes, concepts, and communicating scientific information (National Research Council, 2012). At the start of my study, students could only identify a couple of the SEPs such as experiments and analyzing data with frequency. By the end of my study, students had grown in familiarity and confidence with identifying all of the SEPs and CCCs in their coursework. The SEPs were designed to engage students in all of the processes of science whereas the crosscutting concepts were designed to be practiced in order make science more applicable to our students' everyday lives (National Research Council, 2012 & Goggins et al., 2019). My students stated that some of the crosscutting concepts such as patterns and cause and effect are used in other classes and in everyday life. I believe that this study was a starting point with exposing students to the NGSS nomenclature and goals. Further work is needed to truly encourage three-dimensional learning in science.

This study raised a few questions for further exploration. One thing I wondered after combing over my data is how my data would have looked if I had started my research at the start of the school year instead of in the middle. I also wondered if it would have been possible to incorporate every single SEP and CCC into the four-week treatment unit. I do not think that I was successful here, so I wonder if I should have been more intentional with my planning. I think that my efforts fell short of designing a truly immersive treatment unit; therefore, I think the lack of practice with some of the SEPs and CCCs may have influenced my students' responses to their surveys. Perhaps, I should have pared down my study at the beginning and

only focused on a few select SEPs or CCCs to interweave throughout the periodic table content. In addition, I could have extended my treatment unit to include our next unit as well, which would have focused on different SEPs and CCCs.

Impact of Action Research on the Author

The results of this study will drive my planning and instruction for years to come. Since the NGSS were first distributed nationally in 2014, I have always wanted to integrate the SEPs and CCCs more intentionally into the curriculums I teach alongside the content standards. According to Houseal (2016) when all three components of the NGSS interact, the standard is met. According to Fick (2016), there has been more emphasis on the SEPs and DCIs to teach science standards, but the CCCs play a vital role in three-dimensional science education. After completing my conceptual framework and taking the courses of the MSSE program, I feel confident in designing curriculum that is more intentional about teaching more than just content knowledge. If you look at the NGSS as a whole, content is one third of the components and it should be taught through the lenses of science and engineering practices and crosscutting concepts. Schwarz et al. (2017) pointed out that students are not in the classroom to simply absorb information from their teachers. Instead, students must do the work themselves to form their own knowledge about the phenomena that surround them in their everyday lives. Students cannot passively learn science; they need to be active participants in science.

The purpose of the SEPs and CCCs is to learn science while fostering critical thinking skills. I view my study as a jumping off point that shows more needs to be done in the future to refer to all three dimensions of the NGSS throughout an entire year's worth of curriculum. Next year, I plan to introduce and practice the SEPs and CCCs throughout the first two weeks of

school when we are settling into the course. I plan to look at my chemistry units and intentionally practice at least one SEP and CCC per unit (at a minimum). For example, unit three covers nuclear chemistry. This would be a great time to use the SEP using math and computational thinking when we make half-life graphs through a radioactive decay simulation. This can be paired with the CCC of stability and change to look at how nuclei become stable and change over time through radioactive decay processes which have real world applications.

Upon completion of my Action Research, one of my main takeaways was to use data to drive instruction more intentionally. As educators, we use data all of the time as part of the formative assessment process, but by doing Action Research, I used data a little differently. It was a good change of pace to ask my students specifically how they felt about a topic or to what degree they agreed with a statement in order to drive instruction. I feel that usually I gauge where my students are by looking at work products from my students. However, Action Research reminded me that their voices are just as important to use data to influence my instructional practices and pacing. One thing that did not work the best for my project was the timing of it all. I would have preferred to introduce the SEPs and CCCs at the start of the school year rather than in the middle. Next year, I will not spend two weeks on the SEPs and CCCs as I did this year, but I will introduce them to my students and have one of each that I focus on in each unit we cover—at a minimum.

I would like to discuss my results with my colleagues at MHS and produce a plan to intentionally incorporate the SEPs and CCCs into all of our required science courses. It would be helpful for students to have exposure at all levels in order to enhance their confidence in doing scientific work. Another thing that I would like to do in the future is to truly make at least one

3D style question on each summative assessment to practice the SEPs and CCCs that were utilized and focused on throughout the unit. A 3D style question covers a content standard while using at least one SEP and one CCC to solve. When my students take the state of Michigan science test their junior year (the MSTEP), they will be exposed to only 3D style questions that use the SEPs and CCCs to answer. The classroom vignettes I shared in my conceptual framework support that intentionally using the SEPs and CCCs to learn content will increase three-dimensional scientific learning, which is the overarching goal of the Next Generation Science Standards.

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APPENDICES

APPENDIX A: IRB EXEMPTION

IRB Protocol #2025-2385-EXEMPT APPROVED

From NoReply@TOPAZTI.net <NoReply@TOPAZTI.net>

Date Mon 12/8/2025 2:56 PM

To Gotz, Robyn <robyn.gotz@montana.edu>; Biela-Robinson, Anna <anna.bielarobinson@student.montana.edu>; Szott, Brenna <brenna.szott@montana.edu>

****External Sender****

Hello Biela-Robinson, Anna,

Your protocol was reviewed by the IRB and has been approved.

PI: Biela-Robinson, Anna

Approval Date: 12/8/2025

Title: THE EFFECTS OF IMPLEMENTING SCIENCE AND ENGINEERING PRACTICES AND CROSSCUTTING CONCEPTS ON STUDENT SCIENCE ACHIEVEMENT IN A CONTENT FOCUSED SCIENCE CLASSROOM

Protocol #: 2025-2385-EXEMPT

Review Type: Exemption

Expiration Date: 12/8/2030

Work described under this protocol may now commence. The PI is responsible for ensuring that the protocol accurately describes research practices being conducted.

- > Review Category designation determined by the IRB can be found in the final section of your protocol.
- > Any changes must be submitted via Amendment prior to implementation.
- > Per the Common Rule, research only requires Interim (annual) Review by the IRB if 1) it was reviewed via Full Committee or 2) is regulated by the FDA.
- > All research is subject to post approval monitoring.
- > All protocol types must be renewed 5 years after approval.
- > Inform the IRB once your research is complete so that the protocol may be inactivated.

Please contact your IRB Program Manager with any questions or if you are in need of assistance. Thank you for your diligence in the care of human subjects research participants.

Institutional Review Board for the Protection of Human Subjects | Office of Research Compliance |
Montana State University

Figure A1. IRB Exemption

APPENDIX B: PRE SURVEY—WHAT DOES A SCIENTIST
DO?

Pre Survey: What does a scientist do?

Each year of high school, you are required to take a science course. Last year, you took biology, now you are in chemistry, and next year you will take physics (as well as any electives you choose). Below are a couple of questions to gauge your knowledge of the process and practices of science. Please answer truthfully and honestly.

1. Describe what you think a scientist does. Think, a day at work for a scientist.

2. List as many words you can think of that you associate with scientific practices.

3. Name as many activities from class so far that made you feel like you were being a scientist too.

APPENDIX C: KNOWLEDGE OF SCIENCE AND
ENGINEERING PRACTICES LIKERT PRE SURVEY

Knowledge of Science and Engineering Practices Likert Survey Pre

Below are the eight practices that scientists and engineers use in their daily work. Please rate your familiarity with each by selecting ONE of the choices provided—*Not at all familiar, Somewhat Familiar, Very Familiar, Extremely Familiar*. Each rating is described below:

- Not at all Familiar: You have not heard of this term or have but would not know how to perform this task in class.
- Somewhat Familiar: You have used this term in classes, but do not feel confident with performing this task.
- Very Familiar: You have used this SEP in class often and feel confident in its use.
- Extremely Familiar: You have used this SEP in class, could give examples of how you've used it, and feel confident in its use.

Choose your familiarity with each SEP by circling one of the choices below each that is listed.

SEP #1: Asking Questions/Defining Problems

Not at all Familiar (1) Somewhat Familiar (2) Very Familiar (3) Extremely Familiar (4)

SEP #2: Developing and Using Models

Not at all Familiar (1) Somewhat Familiar (2) Very Familiar (3) Extremely Familiar (4)

SEP #3: Planning and Carrying out Investigations

Not at all Familiar (1) Somewhat Familiar (2) Very Familiar (3) Extremely Familiar (4)

SEP #4: Analyzing and Interpreting Data

Not at all Familiar (1) Somewhat Familiar (2) Very Familiar (3) Extremely Familiar (4)

SEP #5: Using Math and Computational Thinking

Not at all Familiar (1) Somewhat Familiar (2) Very Familiar (3) Extremely Familiar (4)

SEP #6: Constructing Explanations and Solutions

Not at all Familiar (1) Somewhat Familiar (2) Very Familiar (3) Extremely Familiar (4)

SEP #7: Engaging in Argument from Evidence

Not at all Familiar (1) Somewhat Familiar (2) Very Familiar (3) Extremely Familiar (4)

SEP #8: Obtaining, Evaluating, Communicating Information

Not at all Familiar (1) Somewhat Familiar (2) Very Familiar (3) Extremely Familiar (4)

APPENDIX D: KNOWLEDGE OF CROSSCUTTING
CONCEPTS LIKERT PRE SURVEY

Knowledge of Crosscutting Concepts Likert Survey Pre

Below are the seven practices that scientists and engineers use in their daily work to link science to other disciplines. Please rate your familiarity with each by selecting ONE of the choices provided—*Not at all familiar, Somewhat Familiar, Very Familiar, Extremely Familiar*. Each rating is described below:

- Not at all Familiar: You have not heard of this term or have but would not know how to perform this task in class.
- Somewhat Familiar: You have used this term in classes, but do not feel confident with performing this task.
- Very Familiar: You have used this CCC in class often and feel confident in its use.
- Extremely Familiar: You have used this CCC in class, could give examples of how you've used it, and feel confident in its use.

Circle the appropriate choice to indicate your knowledge/familiarity of each crosscutting concept.

CCC #1: Cause and Effect

Not at all Familiar (1) Somewhat Familiar (2) Very Familiar (3) Extremely Familiar (4)

CCC #2: Structure and Function

Not at all Familiar (1) Somewhat Familiar (2) Very Familiar (3) Extremely Familiar (4)

CCC #3: Scale, Proportion, Quantity

Not at all Familiar (1) Somewhat Familiar (2) Very Familiar (3) Extremely Familiar (4)

CCC #4: Patterns

Not at all Familiar (1) Somewhat Familiar (2) Very Familiar (3) Extremely Familiar (4)

CCC #5: Systems and System Models

Not at all Familiar (1) Somewhat Familiar (2) Very Familiar (3) Extremely Familiar (4)

CCC #6: Stability and Change

Not at all Familiar (1) Somewhat Familiar (2) Very Familiar (3) Extremely Familiar (4)

CCC #7: Energy and Matter

Not at all Familiar (1) Somewhat Familiar (2) Very Familiar (3) Extremely Familiar (4)

APPENDIX E: UNIT FOUR PRE TEST: PERIODIC TABLE
AND TRENDS

Unit 4 Periodic Table and Trends Pre: Below is a sample of questions from the Unit 4 summative assessment that specifically focus on using an SEP, CCC, or both to answer successfully.

Use the data below to answer questions 1—3.

Table A1. Experimental data from a periodic table lab.

Element	Element A	Element B	Element C	Element D	Element E
Properties	Produces bubbles when mixed with an acid. Feels cold when mixed with water. Forms a cloudy, white, precipitate.	Turns pink when combined with an indicator. Has a slight temperature change when mixed with water.	Produces bubbles when mixed with acid. Feels cold when mixed with water. Forms a cloudy, white, precipitate.	Feels warm when mixed with an acid. Forms a dark blue precipitate when mixed with a copper solution.	Turns pink when combined with an indicator. Has a slight temperature change when mixed with water.

- ____ A student conducts a laboratory experiment to group together unknown elements. Look at the data table below and use the information to determine which of the elements could be grouped together to make a new column on the periodic table.
 - Elements A, B, C
 - Elements B, C, E
 - Elements D and E
 - Elements A and C
- ____ What crosscutting concept did you use to answer question #1?
 - Patterns
 - Cause and Effect
 - Structure and Function
 - Scale, Proportion, Quantity
- ____ From the table above, which element should the student place by itself?
 - Element A
 - Element B
 - Element C
 - Element D
- ____ Identify the trend for atomic radius on the periodic table.
 - Increases as you move from left to right across the periodic table.
 - Decreases as you move from top to bottom down a group.
 - Remains constant across a period.
 - Decreases as you move from left to right across a period.
- ____ Which of the following factors contributes to a decrease in ionization energy within a group on the periodic table as the atomic number increases down a group?
 - Increase in atomic size.
 - Increase in the size of a nucleus.
 - Increase in the number of electrons
 - Decrease in the number of energy levels and orbitals.

6. ____As ionization energy increases, what happens to atomic radius as you go across a period on the periodic table?
- Elements have atomic radii that are the same size as ionization energy increases.
 - Elements have similar properties across a period.
 - Elements have increasing atomic radii across a period as ionization energy increases.
 - Elements have smaller atomic radii as you move across a period.
7. ____Which of the following correctly describes the relationship between the elements within the same group on the periodic table?
- Elements have atomic radii that are the same size.
 - Elements have similar properties.
 - Elements have the same number of energy levels/orbitals.
 - Elements have increasing ionization energies as you move down.
8. ____A student makes the following claim about the elements on the periodic table: *The elements on the periodic table show many relationships with each other as you move down a group.* Which of the following would NOT be supporting evidence for this claim?
- The metals are all explosive and reactive with increasing reactivity down the group.
 - The noble gases are all unreactive and inert so much so that they are used in daily life such as in signs, welding, and balloons.
 - The lanthanides are all rare Earth elements that are shiny.
 - The halogens are the most reactive nonmetals due to their electronegativities.
9. ____How are the transition metals different from other metallic elements on the periodic table?
- They are more reactive than any other metals on the periodic table.
 - They only react with other metals such as the alkali metals.
 - They are more stable than other metals and are used for many of the materials around us.
 - They are the only metals that have high electronegativities.
10. A scientist discovers a new element in debris from a meteor that struck Earth. Design a testable QUESTION that the scientist could ask in order to help group the element on the periodic table.

APPENDIX F: UNIT FOUR POST TEST: PERIODIC TABLE
AND TRENDS

MULTIPLE CHOICE: Use the data below to answer questions 1—3.

Table A2. Experimental data from a periodic table lab.

Element	Element A	Element B	Element C	Element D	Element E
Properties	Produces bubbles when mixed with an acid. Feels cold when mixed with water. Forms a cloudy, white, precipitate.	Turns pink when combined with an indicator. Has a slight temperature change when mixed with water.	Produces bubbles when mixed with acid. Feels cold when mixed with water. Forms a cloudy, white, precipitate.	Feels warm when mixed with an acid. Forms a dark blue precipitate when mixed with a copper solution.	Turns pink when combined with an indicator. Has a slight temperature change when mixed with water.

- ____ A student conducts a laboratory experiment to group together unknown elements. Look at the data table below and use the information to determine which of the elements could be grouped together to make a new column on the periodic table.
 - Elements A, B, C
 - Elements B, C, E
 - Elements D and E
 - Elements A and C
- ____ What crosscutting concept did you use to answer question #1?
 - Patterns
 - Cause and Effect
 - Structure and Function
 - Scale, Proportion, Quantity
- ____ From the table above, which element should the student place by itself?
 - Element A
 - Element B
 - Element C
 - Element D
- ____ Identify the trend for atomic radius on the periodic table.
 - Increases as you move from left to right across the periodic table.
 - Decreases as you move from top to bottom down a group.
 - Remains constant across a period.
 - Decreases as you move from left to right across a period.
- ____ Which of the following factors contributes to a decrease in ionization energy within a group on the periodic table as the atomic number increases down a group?
 - Increase in atomic size.
 - Increase in the size of a nucleus.
 - Increase in the number of electrons
 - Decrease in the number of energy levels and orbitals.
- ____ As ionization energy increases, what happens to atomic radius as you go across a period on the periodic table?
 - Atomic radius increases
 - Atomic radius decreases
 - Atomic radius stays the same
 - Electronegativity increases

7. ____ Which of the following correctly describes the relationship between the elements within the same group on the periodic table?
 - a. Elements have atomic radii that are the same size.
 - b. Elements have similar properties.
 - c. Elements have the same number of energy levels/orbitals.
 - d. Elements have increasing ionization energies as you move down.
8. ____ A student makes the following claim about the elements on the periodic table: *The elements on the periodic table show many relationships with each other as you move down a group.* Which of the following would NOT be supporting evidence for this claim?
 - a. The transition metals are all explosive and reactive with increasing reactivity down the group.
 - b. The noble gases are all unreactive and inert so much so that they are used in daily life such as in signs, welding, and balloons.
 - c. The lanthanides are all rare Earth elements that are shiny.
 - d. The halogens are the most reactive nonmetals due to their electronegativities.
9. ____ How are the transition metals different from other metallic elements on the periodic table?
 - a. They are more reactive than any other metals on the periodic table.
 - b. They only react with other metals such as the alkali metals.
 - c. They are more stable than other metals and are used for many of the materials around us.
 - d. They are the only metals that have high electronegativities.

Use the diagram below to answer the following questions (10-12).

A blank periodic table grid is shown. The elements are marked as follows:

- A** is located in the first column, second row from the top.
- B** is located in the sixth column, fourth row from the top.
- C** is located in the eighth column, fourth row from the top.
- D** is located in the tenth column, second row from the top.

Figure A2. Blank periodic table with unknown elements A, B, C, D.

10. ____ Which element on the periodic table above is a noble gas?
a. Element A b. Element B c. Element C d. Element D
11. ____ Which elements will easily react with each other?
a. Element A b. Element B c. Element C d. Element D
12. ____ Which element would have an unpredictable number of valence electrons?
a. Element A b. Element B c. Element C d. Element D
13. ____ How did Dmitri Mendeleev arrange the first periodic table?
a. Increasing Atomic Mass c. Increasing Atomic Number

- b. Decreasing Atomic Mass
d. Decreasing Atomic Number
14. ____Mendeleev's periodic table was termed "periodic" for which of the following reasons?
- a. It showed no patterns.
b. It took a long time period for him to construct.
c. The properties of the elements repeated themselves regularly.
d. It left gaps for undiscovered elements.
15. ____If an element is a poor conductor of electricity, it is most likely a
- a. Transition Metal
b. Metalloid
c. Alkali Metal
d. Non-Metal
16. ____Which of the following elements is in the same period as Phosphorous?
- a. Carbon
b. Nitrogen
c. Magnesium
d. Oxygen
17. ____The halogen located in period 5 is....
- a. Fluorine
b. Strontium
c. Xenon
d. Iodine
18. ____Use the information below to determine the number of valence electrons for the element given.

Element Name: Element X

Electron Configuration: $[\text{Ar}]4s^23d^{10}4p^3$

#Valence Electrons: ??????

- a. 3 valence electrons
 - b. 5 valence electrons
 - c. 15 valence electrons
 - d. 2 valence electrons
19. ____ Which element has the highest electronegativity value?
- a. Cesium
 - b. Helium
 - c. Calcium
 - d. Chlorine
20. ____ Which of the following elements has the smallest ionization energy?
- a. Aluminum
 - b. Calcium
 - c. Nitrogen
 - d. Rubidium
21. ____ Which group of elements is arranged by increasing atomic radius?
- a. Sodium, Chlorine, Silicon
 - b. Carbon, Germanium, Tin
 - c. Carbon, Beryllium, Fluorine
 - d. Bromine, Iodine, Fluorine
22. ____ Which of the following elements has the smallest atomic radius?
- a. Hafnium
 - b. Selenium
 - c. Chlorine
 - d. Cadmium
23. ____ Which is TRUE of electronegativity?
- a. The ability of a negative ion to attract another negative ion.
 - b. Electronegativity generally increases as you move from top to bottom within a group.
 - c. Electronegativity is higher for metals than nonmetals.
 - d. Electronegativity generally increases from left to right across a period.

24. ___ Least reactive elements on the periodic table.
25. ___ Made of radioactive elements.
26. ___ The most reactive nonmetals, including solids, liquids, and gases.
27. ___ Elements with 2 valence electrons in their outermost energy levels.
28. ___ Elements with variable numbers of valence electrons that fill the d orbitals.
29. ___ The most reactive metals with very low boiling points.
30. ___ Elements known as the rare Earth metals with electrons in the f orbitals.

Use the diagram below to determine the missing elements. Fill in the NUMBER of the element in the blank portions of the periodic table.

- | 31. | Element | Description |
|-----|---------|---|
| 1 | | an intensely reactive alkali metal with an electrons configuration of $[\text{Ne}]3s^1$ |
| 2 | | is unreactive and used in balloons; nucleus is an alpha particle |
| 3 | | a nonmetal that exists as graphite and diamonds; found in every living thing |
| 4 | | halogen used to disinfect water; commonly found in table salt |
| 5 | | transition metal that forms strong durable alloys; readily corrodes to form rust |
| 6 | | alkaline earth metal that provides the white color in fireworks |

Li	Be			B	Ne
				Si	Ar
K	Ca	Cr	Mn		Ga
Rb	Sr	Mo	Tc	Ru	Ge
Cs	Ba	W	Re	Os	As
					Se
					Br
					Kr
					Xe
					Rn

Figure A3. Periodic table with missing elements to identify.

32. An element has similar chemical properties as selenium and oxygen. It has an atomic number greater than krypton, but less than iodine. What is the mystery element's identity? Explain the reasoning behind your choice.

33. A scientist discovers a new element in debris from a meteor that struck Earth. Design a testable QUESTION that the scientist could ask in order to help group the element on the periodic table.

34. Mendeleev was a scientist that is known as the father of the periodic table. Explain the scientific processes used in order to construct the first periodic table.

35. Choose an element from each of the two groups below from the periodic table. Fill out the missing information about the elements in the table below.

Table A3. Application of element properties and trends.

	Group 1 Element	Group 17 Element
Element Chosen		
Group/Family Name		
Number of Valence Electrons		
Comparison of Atomic Radius		
Comparison of Ionization Energy		
Comparison of Electronegativity		
Name an element with similar properties		

APPENDIX G: POST SURVEY—WHAT DOES A SCIENTIST
DO?

Post Survey: What does a scientist do?

The past two units, we have been learning our chemistry content along with the practices that scientists use in their daily work. Answer the questions below to the best of your ability.

1. What practices do scientists use that help them complete their work?
2. List as many words you can think of that you associate with scientific practices.
3. Has your attitude changed at all about science as we have learned about and explicitly used the SEPs and CCCs. How?
4. We have spent quite a bit of our unit learning about what scientists do and the practices they use. Rate each of the following statements (circle your choice).
 - **I could describe what practices a scientist might use in their daily work.**
Strongly Disagree Disagree Agree Strongly Agree
 - **I can describe the scientific practices that were used to construct the periodic table.**
Strongly Disagree Disagree Agree Strongly Agree
 - **I can differentiate between a SEP and a CCC**
Strongly Disagree Disagree Agree Strongly Agree
 - **I can relate the activities that we do in class to SEPs and CCCs**
Strongly Disagree Disagree Agree Strongly Agree

APPENDIX H: KNOWLEDGE OF SCIENCE AND
ENGINEERING PRACTICES LIKERT SURVEY POST

Knowledge of Science and Engineering Practices Likert Survey Post

Below are the eight practices that scientists and engineers use in their daily work. Please rate your familiarity with each by selecting ONE of the choices provided—*Not at all familiar, Somewhat Familiar, Very Familiar, Extremely Familiar*. Each rating is described below:

- Not at all Familiar: You have not heard of this term or have but would not know how to perform this task in class.
- Somewhat Familiar: You have used this term in classes, but do not feel confident with performing this task.
- Very Familiar: You have used this SEP in class often and feel confident in its use.
- Extremely Familiar: You have used this SEP in class, could give examples of how you've used it, and feel confident in its use.

Choose your familiarity with each SEP by circling one of the choices below each that is listed.

SEP #1: Asking Questions/Defining Problems

Not at all Familiar (1) Somewhat Familiar (2) Very Familiar (3) Extremely Familiar (4)

SEP #2: Developing and Using Models

Not at all Familiar (1) Somewhat Familiar (2) Very Familiar (3) Extremely Familiar (4)

SEP #3: Planning and Carrying out Investigations

Not at all Familiar (1) Somewhat Familiar (2) Very Familiar (3) Extremely Familiar (4)

SEP #4: Analyzing and Interpreting Data

Not at all Familiar (1) Somewhat Familiar (2) Very Familiar (3) Extremely Familiar (4)

SEP #5: Using Math and Computational Thinking

Not at all Familiar (1) Somewhat Familiar (2) Very Familiar (3) Extremely Familiar (4)

SEP #6: Constructing Explanations and Solutions

Not at all Familiar (1) Somewhat Familiar (2) Very Familiar (3) Extremely Familiar (4)

SEP #7: Engaging in Argument from Evidence

Not at all Familiar (1) Somewhat Familiar (2) Very Familiar (3) Extremely Familiar (4)

SEP #8: Obtaining, Evaluating, Communicating Information

Not at all Familiar (1) Somewhat Familiar (2) Very Familiar (3) Extremely Familiar (4)

Likert Survey Free Response Explanations:

1. Which SEP do you feel the most confident using?

Explain the reasoning for your choice:

2. Which SEP do you feel the least confident using?

Explain the reasoning for your choice:

APPENDIX I: KNOWLEDGE OF CROSSCUTTING
CONCEPTS LIKERT SURVEY POST

Knowledge of Crosscutting Concepts Likert Survey Post

Below are the seven practices that scientists and engineers use in their daily work to link science to other disciplines. Please rate your familiarity with each by selecting ONE of the choices provided—*Not at all familiar, Somewhat Familiar, Very Familiar, Extremely Familiar*. Each rating is described below:

- Not at all Familiar: You have not heard of this term or have but would not know how to perform this task in class.
- Somewhat Familiar: You have used this term in classes, but do not feel confident with performing this task.
- Very Familiar: You have used this CCC in class often and feel confident in its use.
- Extremely Familiar: You have used this CCC in class, could give examples of how you've used it, and feel confident in its use.

Circle the appropriate choice to indicate your knowledge/familiarity of each crosscutting concept.

CCC #1: Cause and Effect

Not at all Familiar (1) Somewhat Familiar (2) Very Familiar (3) Extremely Familiar (4)

CCC #2: Structure and Function

Not at all Familiar (1) Somewhat Familiar (2) Very Familiar (3) Extremely Familiar (4)

CCC #3: Scale, Proportion, Quantity

Not at all Familiar (1) Somewhat Familiar (2) Very Familiar (3) Extremely Familiar (4)

CCC #4: Patterns

Not at all Familiar (1) Somewhat Familiar (2) Very Familiar (3) Extremely Familiar (4)

CCC #5: Systems and System Models

Not at all Familiar (1) Somewhat Familiar (2) Very Familiar (3) Extremely Familiar (4)

CCC #6: Stability and Change

Not at all Familiar (1) Somewhat Familiar (2) Very Familiar (3) Extremely Familiar (4)

CCC #7: Energy and Matter

Not at all Familiar (1) Somewhat Familiar (2) Very Familiar (3) Extremely Familiar (4)

Likert Survey Free Response Explanations:

1. Which CCC do you feel the most confident using?

Explain the reasoning for your choice:

2. Which CCC do you feel the least confident using?

Explain the reasoning for your choice:

APPENDIX J: TEACHER JOURNAL OBSERVATIONS

Teacher Journal Potential Observations:

- Day, Activity, SEPs/CCCs focused on.
- Student attitudes towards the activity and notes from conversations.
- Reflection:
 - Strengths of the activity...what went well?
 - Weaknesses of the activity...where did students struggle; how could it be improved?

APPENDIX K: STUDENT INTERVIEW QUESTIONS

List of Student Interview Questions:

Note: Answering these questions will have no impact on your grade in this class. I appreciate you donating your time to share your thoughts!

1. Do you feel confident describing to a friend what a scientist does? Why or Why not?
2. What activities have we engaged in that made you feel like you were “doing science”?
3. Do you feel confident describing SEPs and CCCs in your classwork? Explain.
4. Which SEPS/CCCs do you recall using in biology last year or throughout our first few units this year?