

CROSSCUTTING CONCEPTS AS LANGUAGE FOR REASONING
AND SENSEMAKING IN HIGH SCHOOL EARTH SCIENCE

by

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DEDICATION

Dedicated to all the people in my life who made this journey not only possible but a wonderful experience. My husband for his constant faith in me and his willingness to listen as I talked through all the puzzles in my head. The outstanding teaching community at Flathead High School who continuously inspire me with their professionalism and passion for this adventure we call teaching, and my students who were carried along on this learning journey with me.

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ABSTRACT

The Disciplinary Core Ideas for High School Earth Science are filled with information relevant to many challenges humans are facing across the globe. To benefit from this growing body of knowledge, it is increasingly important that we support students in improving reasoning and communication as part of scientific literacy. This research explored the impact direct instruction of Crosscutting Concepts had on recognition of the CCC's across content, detail and specificity of reasoning, and self-efficacy related to science communication in high school Earth Science students. Students were divided into two groups one receiving direct instruction related to Crosscutting Concepts through mini lessons and specific classroom tools and templates. The non-treatment group experienced the same content and general references to Crosscutting Concepts but did not receive direct instruction. Mixed methodology was used to collect quantitative and qualitative data using surveys, formative assessment through Interactive Science Notebooks and Misconception Probes and summative assessments through content specific unit tests.

Students in both groups made progress in recognition of Crosscutting Concepts with students in the treatment group reporting more confidence in this skill. Interviews, and observation showed students in the treatment group were more likely to see connections to Crosscutting Concepts across topic areas and use the CCC's in discussion. Survey results showed direct instruction increased students' perception of value in applying Crosscutting Concepts in their reasoning. There was not a significant difference in the specificity and detail of reasoning between treatment and non-treatment groups. Results suggest that these same methods can improve recognition of Crosscutting Concepts across content, increase self-efficacy related to communicating science ideas and contribute to a common language in the classroom that can be used by students to support each other's thinking and focus discussion and exploration of phenomenon.

CHAPTER ONE

INTRODUCTION AND BACKGROUND

Context of the Study

Tucked in mountains of northwest Montana, Kalispell sits along the Flathead River between Glacier National Park and Flathead Lake. This valley is part of the traditional territory of the Bitterroot Salish, Kootenai, and Pend d'Oreille tribes, and I want to acknowledge those who have stewarded this land throughout the generations. Europeans settled this valley as an agricultural and logging community and recent years have seen it shifting more toward tourism, healthcare and small businesses as people choose to visit and sometimes stay in this beautiful valley. The past decade has been one of steady growth in Kalispell with a 2.6 % annual growth rate and a current population of approximately 25,000 in the city and 99,800 in Flathead County (U.S. Census 2020). Established in 1903 Flathead High School is the first of two public high schools currently serving Kalispell and has a rich connection to the community and its history, often having families with multiple generations of Flathead High school graduates. According to my Principle Michele Paine (2021) Flathead enrollment for the 2021-2022 school year Flathead included 1489 students 0.3% Black or African American, 1.1% American Indian or Alaska Native, 0.7% Asian, 2.5% Hispanic or Latino, 0.4% Native Hawaiian or Pacific Islander, 1.8 % two or more races and 93% white from the city and surrounding Flathead County. Historically Flathead has often qualified as a Title I school with the primary data source for this determination tied to the number of students using and eligible for free and reduced lunch. Due to the Covid-19 pandemic breakfast and lunch are currently being offered for free to all students, so accurate Title I data for this school year is not available. The state of Montana administers the

ACT to all juniors as a standardized statewide assessment. When using data available from Montana Office of Public Instruction (2021) to compare with other high schools for 2020-2021 students at FHS had an average score in science of 19 as compared to a state average of 19.4. Graduation rates for Flathead were 80.9 % for 2019-2020 school year below the state average of 85.9%.

In Montana students are required to take two years of lab-based science to complete graduation requirements. Flathead High school requires all freshman take Biology while sophomores have several classes to choose from including Chemistry, Earth Science or Conceptual Physical Science split into semester physics/semester chemistry. On average, 50% of our students fulfill the second year of this requirement with Earth Science. I worked with students in my Earth Science classes for purposes of my Action Research Project. Our student registration guide describes Earth Science:

“as a lab-based course that explores the systems of the earth and space systems, giving students the opportunity to discover how the dynamic earth affects their lives. Students will make connections involving human interactions with our earth systems and the environment. Investigations will improve student skills in the science practices including asking questions, planning and carrying out investigations, interpreting data, constructing explanations and arguing from evidence.” (Registration 2021)

I grew up in Montana and came to education as a second career after spending a few years working in natural resources. I have been working at Flathead High School since 2008 teaching in various content areas including Chemistry, Introductory Biology, IB Environmental Systems and Societies and most recently Earth and Space Science. One of my goals as an educator is to help my students find value in what a science class has to offer. Increasing the knowledge and understanding of scientific content and phenomenon is a wonderful result, but ultimately helping my students gain respect for scientific thinking has broad benefits. The

expectations for high school science education have shifted, and skills related to scientific reasoning and communication have gained emphasis as our access to knowledge and information has expanded. The Framework for K-12 Science Education (National Research Council, 2012) and the Next Generation Science Standards (NGSS Lead States, 2013) outline three dimensions to frame science education including Disciplinary Core Ideas (DCI), Science and Engineering Practices (SEP), and Crosscutting Concepts (CCC). The intent is that these three dimensions are interwoven and incorporated across all levels of learning. The Framework explains that the CCCs can “help provide students with an organizational framework for connecting knowledge from the various disciplines into a coherent and scientifically based view of the world” (National Research Council, 2012, p. 83). I could see the potential for deep understanding as students were coached and supported using the crosscutting concepts but realized my methods had been inconsistent and needed improvement. The purpose of my Action Research was to investigate the efficacy of direct instruction to incorporate the CCC’s in course work, with intent to help students improve their scientific reasoning and communication and recognize value in what they are learning. These are skills that can be practiced across all branches of science and would benefit all students.

Focus and Research Question

Teaching earth science is an opportunity to provide students with connection to many phenomena, and systems that shape the world around them every day. This is a tantalizing possibility, but like many teachers, I observe a very broad spectrum of interest and motivation related to high school science. This seems to manifest in a lack of value in science in general, missed connections between science and general life skills, and frustration compounded by a

lack of confidence when communicating about science concepts and ideas. Teaching several different science subjects over the years I have witnessed similar patterns in student skills and progress in numerous content areas. I personally experienced a lack of methodologies for explicitly teaching students about reasoning in a science context. This gap manifested in student outcomes where explanations or reasoning was vague, often not clear enough for me to be certain of the understanding. While I spent plenty of class time asking students to provide reasoning or justification for their conclusions, I realized I lacked a consistent effective method or set of tools for helping students learn how to do this. Some students seem to pick up on reasoning well from the examples and templates I have used, but I have not found widespread consistent success for students with my current methods. The essential question for my action research was formulated with a variety of factors in mind including: a wide range of academic ability, student attitude and confidence related to communication in science and the importance of crosscutting concepts as described by the Next Generation Science Standards.

Focus Question

My focus question was, To what extent does the direct instruction of crosscutting concepts impact student reasoning and communication in high school Earth Science?

My sub-questions include the following:

1. To what extent does the direct instruction of crosscutting concepts impact student ability to recognize the crosscutting concepts across different contexts or topics?
2. To what extent does direct instruction of crosscutting concepts impact the detail and specificity of reasoning in CER writing format?

3. To what degree will incorporation of crosscutting concepts affect student self-efficacy related to ability to communicate scientific reasoning?

In my experience, all students could benefit from development of a common language and skills to help them clearly communicate reasoning and ideas derived from observations and experience in science. While my research was in the context of Earth Science it is not unreasonable to suggest that my findings related to the impact of incorporation of crosscutting concepts will be a benefit to the whole science department. The broad application is one reason the topic has so much appeal to me, the potential support of instruction methods in any science class I teach and students at any level.

CHAPTER TWO

CONCEPTUAL FRAMEWORK

Characterized as the science slump, the general disengagement with school that can manifest in middle and high school seems to be even more pronounced in science. Beyond students seeing an intrinsic interest value, there are other possibilities to overcome the science slump that include helping students recognize utility or usefulness value, and helping students make a connection to a sense of self. While these are not presented as a one size fits all quick fix, it does provide some aspects that might lend to new opportunities for connections and applications of the cross-cutting concepts (Shumow et al., 2014).

Using the crosscutting concepts could help students develop a language to communicate about science understanding that is not specific to any particular content. They would be able to apply their knowledge to new developments or situations. This contributes to the idea that more information may be added continually, and we can examine new ideas through a lens of patterns, cause and effect or scale that will help enhance our understanding. In other words, use of crosscutting concepts supports an expectation of scientific literacy and lifelong learning as opposed to mastery of the currently known facts or information. Having a familiar reliable vocabulary like crosscutting concepts, that can apply to many topics and stages of reasoning could help students make connection, improve their confidence, and lower their frustration. To explore this idea more thoroughly I investigated the impact direct instruction of crosscutting concepts on student reasoning, communication, and self-efficacy related to these skills.

Scientific Literacy and Sense Making

People often use reasoning in daily life as we consider information, solve problems, organize tasks, and plan a course of action. Kind and Osborne (2008) would argue that science education has suffered from a lack of clarity about what we want when it comes to scientific reasoning. Various attempts have been made to clarify expectations for reasoning. The National Research Council (2012) identifies reasoning as a skill in a Framework for K-12 Education, specifically in the Claim-Evidence-Reasoning format for writing that is used widely by science educators. Connecting to previous knowledge, making observations of phenomena, asking questions, analyzing results, and drawing conclusions all utilize a student's personal reasoning. Reasoning as an aspect of scientific literacy emphasizes not only what students know about science, but how and why they know something. The concept of scientific literacy is certainly not new and while a consensus of what it means to be scientifically literate is elusive there is wide agreement about the importance. Many definitions have emerged with one comprehensive list including the descriptions: "independence in learning science, the ability to think scientifically and the ability to use science knowledge in problem solving" (Norris & Phillips 2003, p. 205). Norris et al. (2014) continued the research and analyzed 74 articles that included descriptions of scientific literacy. They concluded that the objectives of scientific literacy can be divided into three the categories: knowledge of content, capacities, and traits. Yet another way of looking at it might be to ask, "What do people know?" "What people do?" and "What do people value?" (Gräber, 2001). Scientific literacy can also be linked to the goal of developing lifelong learners. This speaks to the fact that information is continually evolving, and students need to be "ready to deal with an information landscape that is continually growing in size and complexity" (Holden, 2012, p. 108). In reviewing the numerous interpretations of scientific literacy there is a

common theme that points toward application of knowledge and scientific thinking that could be described as scientific reasoning.

Another way to consider reasoning is as the articulation of sensemaking. According to Kappon (2017) this perception of learning involves “a complex process of sensemaking in which a learner constructs and reconstructs a series of self-explanations that evolve, change, replace one another, or merge into a new self-explanation” (p. 166). According to Cannady et al. (2019) mechanistic reasoning is identified as one of several sub-constructs crucial to understanding scientific phenomenon, and the potential for content specific instruction to improve students’ ability with this skill. The findings go on to support the conclusion that approaching science learning as sensemaking with a broad set of competencies (including reasoning) enables students to better understand the content through a wide variety of instructional methods (Cannady, 2019). For the purposes of this study scientific reasoning will be considered a necessary aspect of scientific literacy, broadly defined as “the thinking skills involved in inquiry, experimentation, evidence evaluation, inference and argumentation that are done in the service of conceptual change or scientific understanding” (Zimmerman, 2005, p. 1).

Defining the Crosscutting Concepts.

Next Generation Science Standards are divided in to three dimensions including Disciplinary Core Ideas (DCI’s), Cross Cutting Concepts (CCC’s), and Science and engineering Practices (SEP’s) (NGSS Lead States, 2013). The crosscutting concepts are described in *A Framework for K-12 Science Education* (2012) as “concepts that bridge disciplinary boundaries, having explanatory value throughout much of science and engineering” (p. 83). These broad concepts are like threads that connect a multitude of concepts that would otherwise be studied

independently depending upon the topic or discipline of focus. Summarized by the San Diego Department of Education (2015), the CCC's can be identified individually, or grouped to show connections between patterns, causality, and systems (Figure 1).

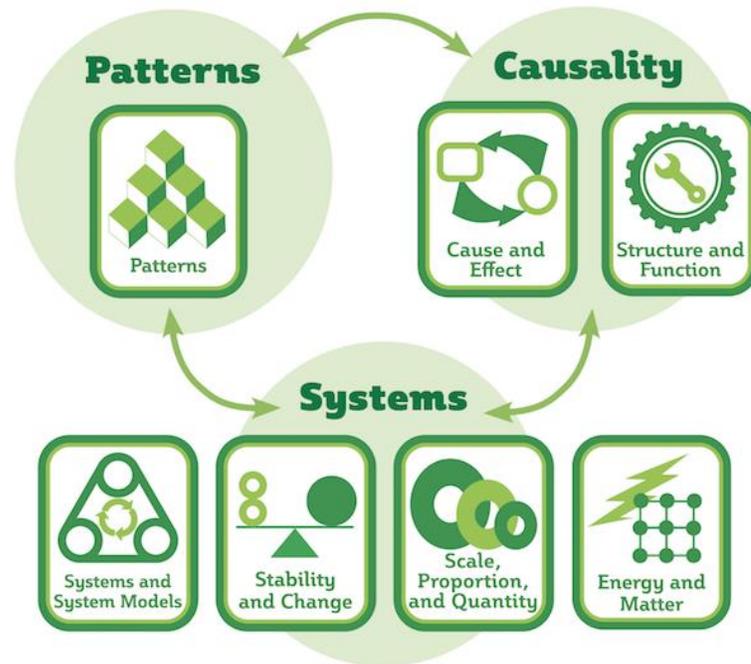


Figure 1. Summary graphic of seven cross cutting concepts organized by systems, patterns and causality (San Diego County Office of Education, 2015).

While there are many ways these concepts can be organized, any summarization, grouping, or identification of overlap related to the CCC's is likely best served by a clear understanding of the individual concepts. *A Framework for K-12 Science Education* (2012) describes the crosscutting concepts in detail:

1. **Patterns:** Observed patterns in nature guide organization and classification and prompt questions about relationships and causes underlying them.
2. **Cause and Effect:** Events have causes, sometimes simple, sometimes multifaceted. Deciphering causal relationships, and the mechanisms by which they are mediated, is a major activity of science and engineering.

3. Scale, proportion, and quantity. recognize what is relevant at different size, time, and energy scales, as well as proportional relationships between different quantities as scales change.
4. Systems and system models. organized group of related objects or components; models can be used for understanding and predicting the behavior of systems.
5. Energy and matter: Flows, cycles, and conservation. Tracking flows of energy and matter into, out of, and within systems helps one understand the systems' possibilities and limitations.
6. Structure and function. The way in which an object or living thing is shaped and structured determines many of its properties and functions.
7. Stability and change. For natural and built systems alike, conditions of stability and determinants of rates of change or evolution of a system are critical elements of study. (Chapter 4)

While the CCC's can, and should be defined individually, the consideration of these concepts in the context of real-life observation often reveals multiple connections. Take for example the traditional Earth Science topic of wind during a unit about weather. Patterns related to wind can be described by direction, force or even time of day, and to explain these patterns we might look to cause and effect. That leads to the connections between energy flow and how that impacts stability and change of airmasses. To expand our investigation even more we could look at different scales, how energy is transferred between molecules, or how global wind patterns result in mixing of air and lead to large scale phenomena like jet streams and polar vortex. In chemistry the periodic table is a direct example of patterns, while stoichiometry and thermodynamics could both benefit from incorporation of flow of energy and matter as well as scale and proportion (Cooper, 2020). There are examples across all disciplines, and this general strategy connecting new information to larger concepts is related to how people learn as supported by ongoing research (National Academies of Sciences, 2018).

The Role of Crosscutting Concepts

The Next Generation Science Standards are clearly and intentionally three dimensional. The idea of different dimensions is not new, however previously science themes, unifying concepts or cross cutting ideas were included only as supplements. The innovative shift that has taken place with the NGSS is in the equal integration of all three dimensions (PEEC, 2017). Some would argue for styles of reasoning as a more coherent model than the crosscutting concepts (Osborne, 2017). Most agree however, that using the crosscutting concepts can provide a consistent language for teachers to communicate with students, and aid in prompting student responses (Council of Chief State School Officers, 2017). There are other potential integrations as well, Cooper (2020) explains how the CCC's can act as bridges across phenomena, be used as tools or lenses to deepen understanding or help define the rules of the game or scientific norms.

When Crosscutting Concepts are used to describe observations and formulate questions related to a phenomenon, students can focus on different aspects they might recognize, or articulate details that are puzzling, and potentially use CCC's as the foundation for investigation.

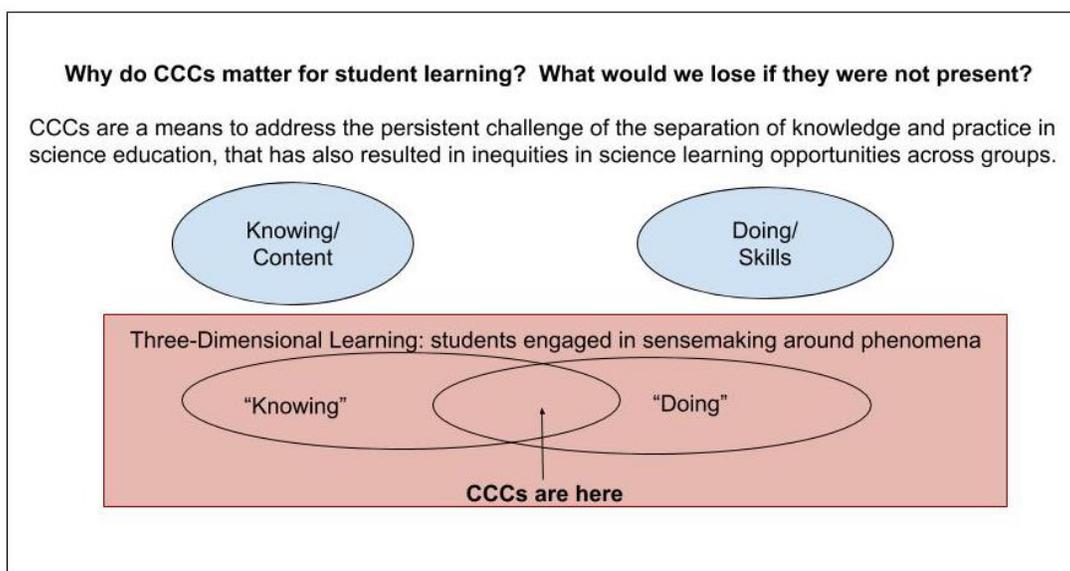


Figure 2. The Role of CCC's in Three Dimensional Learning at the intersection of Knowing and Doing and relationship to traditional approaches to science (Fick et al., 2019).

Fick et al. (2019) considered the role of the crosscutting concepts in Figure 2. This model allows for different knowledge and background that students may bring with them as well as learning shifts that happen during study. The crosscutting concepts are central and student interaction and engagement is necessary, playing a role in each student's construction of their own understanding. According to a Framework for K-12 Science Education "Equity in science education requires that all students are provided with equitable opportunities to learn science and become engaged in science and engineering practices" (p. 28). Incorporation of crosscutting concepts as the language of science is an equitable practice as it draws on any experience or observation seeking to incorporate the crosscutting concept of focus (Frost, 2022). It is less likely a student will feel left out if their personal experience varies from their peers when using a crosscutting concept as the common connection. The more variety of examples and context students can provide makes for a richer experience for all individuals. In an education setting this model provides flexibility that can still be a consistent anchor for planning and incorporation of CCC's in the investigation of phenomenon and progress through different disciplinary core ideas.

Best Practices for Teaching Crosscutting Concepts

Crosscutting concepts can apply to a variety of topics and logically can be incorporated into existing best practices for teaching science. Constructivism is the idea that learning is an evolutionary process in which learners constantly adapt incoming information to fit their preconceptions as they reconstruct their understandings (Llewellyn, 2013). Providing students with practice applying the Crosscutting Concepts to new context fits well with this constructivist approach. This constructive process can be hampered by misunderstandings, in Page Keely's

book *Science Formative Assessment Vol. 1* (2016) she explains that “the consistent use of formative assessment allows teachers to identify problem learning areas and encourages students to examine their ideas and share how and why they have changed” (p. 21). Misconception probes can be a formative tool and method to assess progress in this stage of learning. As described in *Science Teaching Reconsidered: A handbook* (1997) learning progress can be supported by first identifying the misconception, next providing a forum for students to confront their misconceptions, and finally supporting students to reconstruct their knowledge, based on scientific models.

Interactive Science Notebooks can be used to foster constructivism and provide additional formative assessment options as they combine teacher directed input with student directed reflection and processing. Research conducted with fourth grade students in Kentucky, found that incorporation of Interactive Science Notebooks as a learning tool during science instruction, had a positive influence on student self-efficacy in expressing science content knowledge. Seventy six percent of the students studied had an increase in the overall attitudes about science (Krachenfels, 2019). According to Waldeman and Kent (2009) “Interactive Science Notebook (ISN) can be a powerful instruction tool, allowing students to take control of their learning while processing information and engaging in self-reflection” (p. 51). As stated by the Chief Council of School State Officers (2017) in *Using Crosscutting Concepts to Prompt Student Responses* “When teachers’ prompts are structured with the crosscutting concepts, the focus of student thinking can be directed to key aspects of the phenomenon, the system being investigated, and/or patterns that may be used as evidence to support explanations or arguments for the causes of a phenomenon” (p. 5).

Action research related to reasoning and direct instruction of the CCC's has yielded mixed results. Working with 7th grade science students, Poland (2018) used two units incorporating explicit instruction in the use of cross cutting concepts. Student progress was measured using written responses to specific CCC analysis questions and explanations using a claim-evidence-reasoning format initially with specific prompting to use CCC's and finally without prompting. Final evaluation showed a 27% increase in the number of students who identified and used a cross cutting concept in their writing without prompting. Students who used Crosscutting Concepts also were closer to meeting grade level writing expectations while 87% of students who did not use CCC's scored below grade level. Poland's interviews with students suggested that learning the CCC's helped them feel more confident in their writing because they felt like they had a place to start.

Direct instruction in the structure and content of a scientific argument has been shown to improve this skill in students. Students in Australia who received explicit instruction regarding the components of an argument and how to argue in a scientific manner were compared to a control group. Students receiving explicit instruction had medium to large gains in the detail and specificity of reasoning, and content specific scores also improved (Venville, 2010). In a more recent study students in a high school Earth Science class received explicit instruction around Crosscutting Concepts paired with proficiency grading as part of action research. A proficiency scale for crosscutting concepts was used to measure progress, and results showed no significant difference between the use of CCC pre and post-test. Students did not receive direct instruction in all crosscutting concepts but did show improved confidence in use of patterns and structure and function in post surveys, two concepts that were explicitly addressed (Fitch, 2019).

A Need for More Research

In a summit convened to examine the potential support crosscutting concepts can provide to three-dimensional learning it was noted “there does not yet exist a robust research base with respect to how students learn about CCCs or the role they play in supporting students’ science learning and ability to integrate science ideas reliably across a range of contexts” (Fick, 2019, p. 5). Several challenges in evaluating existing research include studies that are mostly theoretical or focus on a single crosscutting concept. Also related studies are elusive as language is widely varied and may not match with current NGSS vocabulary making it difficult to clarify connections (Fick, 2019). Participants at the summit examining crosscutting concepts and support of three-dimensional learning identified key areas for future research including curriculum and instruction with one sub-question “Is learning improved with intentional foregrounding (of CCC’s) and sequencing across the school year?” (Fick, 2019, p. 76) Investigating how direct instruction of crosscutting concepts impacts reasoning and communication could contribute to the understanding of this question.

CHAPTER 3

METHODOLOGY

Students across a broad range of ability and experience can benefit from improvements in reasoning and practice related to communication in science. Action research was carried out to explore the question; To what extent does the direct instruction of Crosscutting Concepts impact student reasoning and communication in high school Earth Science? Sub questions related specifically to recognition of Crosscutting Concepts, improvements in written reasoning and self-efficacy related to science communication were identified to help consider different aspects of student work. Direct instruction strategies were used with the treatment group for four months and data collection was carried out using a mix of quantitative and qualitative methods as part of both formative and summative assessment. These methods provided a range of responses from written to verbal, both formal and more informal in the attempt to document outcomes for a broad range of students.

Demographics

Next Generation Science Standards specify the incorporation of seven Cross Cutting Concepts (CCC). My question investigated the impact that direct instruction of these concepts might have on student use and recognition of the CCC's in scientific reasoning and sensemaking as well as self-efficacy related to these skills. I worked with four sections of Earth Science students ($N=67$). For purposes of this research, each section was assigned a research group, either treatment or standard instruction. Each research group was comprised of one morning and one afternoon section with a mix of abilities, and gender throughout resulting from standard school procedures in student scheduling. The treatment group consisted of 22 male and 14

female students and included three students with IEP's and one English as Second Language student. The non-treatment group was composed of 21 male students, nine female students and one non-binary student and included two students with IEP's and one English as Second Language student. Both groups experienced the same classroom conditions, topics, general instruction, and resources. The treatment group received direct instruction, tools, and scaffolding related to crosscutting concepts and use in reasoning. Using a mixed method design I collected data with both quantitative and qualitative techniques. The research methodology for this project received an exemption by Montana State University's Institutional Review Board, and compliance for working with human subjects was maintained (Appendix A).

Treatment

Throughout the first quarter of the school year (approximately two months) all students received the same methods of instruction and content which allowed time for building classroom routines and culture and relationship development between my students and I as instructor. Posters and signage in my classroom include lists, symbols and examples of Crosscutting Concepts and Science and Engineering Practices. This provides all students with visual reminders of these skills and concepts that are referred to throughout the year. During the first weeks of the year all students did initial set up and learned the format for interactive science notebooks. Use of interactive science notebooks is part of my usual practice and I have found it effective in helping students not only organize information but show their thinking and apply science practices. All student also received instruction and opportunities to practice the Claim-Evidence-Reasoning (CER) writing structure. Templates for CER writing, along with a rubric for

notebooks and reflections were provided to students and secured in the reference section of their notebooks (Appendix B).

During the four-month research period I used three strategies exclusively with the treatment group to provide front loading, direct instruction and resources related to crosscutting concepts and the use in reasoning and sense making. First students were provided with a set of cards for the CCCs (Appendix C) developed by Paul Anderson and available on the website Wonder of Science. The cards were kept in their interactive notebooks and students were asked to refer to these cards during observation/discussion of a phenomenon, during writing or other appropriate class activity. Next, I delivered a mini lesson at or near the beginning of a new unit or topic with a focus on one specific crosscutting concept. Each mini lesson was between 7-10 minutes focused on one CCC I felt would be particularly relevant to that topic. For example, Earths Changing Surface is a major topic in Earth Science. Prior to exploring topics in this unit including earth systems and plate tectonics I used a mini lesson on stability and change using a notes organizer from Wonder of Science (Appendix D). The phenomenon used was a melting ice cube, both in real time in the room, and as a time lapse clip showing a melting ice cube. I identified the system and shared my thinking about stability and change of the ice. Students added notes to their organizer, then were asked to add independent observations and discuss with a partner prior to sharing out as a whole class discussion, this is a strategy often referred to as a Think-Pair-Share. The mini lessons used throughout the research period followed similar strategies and are summarized in Table 1.

Table 1. Summary list of Crosscutting Concept mini lessons embedded in content units.

CCC mini lesson	Content Unit/Topic
Cause and Effect Energy & Matter	Climate Change – Greenhouse gases and Earth’s energy balance
Stability & Change	Earths Changing Surface - Plate tectonics
Structure & Function Patterns	Earth’s Changing Surface – GPS Measuring Earth Surface Volcanic systems and viscosity
Systems & System models	Earths Changing Surface – Glaciers and River Systems
Scale Proportion & Qty	Geologic Time

Finally, I developed a thinking frame used by students during lessons that requires students to choose a crosscutting concept of focus, then consider and describe what they notice and what they might wonder with reference to that CCC (Appendix E). Students in the treatment group were provided with this thinking framework following initial use of misconception probes, as well as when considering phenomena, or experimental results following two misconception probes, at various opportunities during observations, discussion and prior to written reflection.

Data Collection and Analysis Strategies

Various data collection strategies were incorporated throughout the study period which began early in the second quarter and was completed just after the end of third quarter. The Science Perspectives and Crosscutting Concepts Survey was administered at the beginning and end of the study. In the interim formative assessments included Crosscutting Concept practice tasks and Reflections completed in Interactive Science Notebooks along with Earth Science Misconception Probes. Summative assessment was completed using Crosscutting Concept

Application Questions on unit tests and quizzes. The final piece of data was the Science Learning Interview with focus groups at the completion of the study. A summary of these instruments and the research question they were intended to address is found in the Data Triangulation Matrix (Table 2).

Table 2. Data Triangulation Matrix.

	Data Collection Methods		
Research Questions	Source 1	Source 2	Source 3
To what extent does the direct instruction of crosscutting concepts impact student ability to recognize the crosscutting concepts across different contexts or topics?	Science Perspectives and Crosscutting Concepts Survey	Science Notebook Unit Reflection	Crosscutting Concepts Practice Tasks
To what extent does direct instruction of crosscutting concepts impact the detail and specificity of reasoning in CER writing format?	Crosscutting Concepts Practice Tasks	Crosscutting Concept Application Questions	Earth Science Misconception Probes
To what degree will incorporation of crosscutting concepts affect student self-efficacy related to ability to communicate scientific reasoning?	Science Perspectives Crosscutting Concepts and Survey	Science Notebook Unit Reflection	Science Learning Interviews

During the four-month period a variety of Earth Science topics were addressed generally. Science Perspectives and Crosscutting Concepts Survey was administered to all students as a pre and a post assessment. This Likert style survey was modeled after the Student Attitudes Toward

STEM (S-STEM) survey created by the Friday Institute for Educational Innovation (2012).

Original statements were written to more closely fit my specific research questions including six statements related to recognition and use of Crosscutting Concepts in science communication and six statements that address student's perceptions of their success and ability in science in general. Students indicated their level of agreement with each statement using a five-point scale with 5 indicating strongly agree, 4 agree, 3 neutral, 2 disagree and 1 strongly disagree (Appendix F). For coding purposes during analysis, the statements with a negative science perspective were reversed with a value of 5 for strongly disagree to 1 for strongly agree. Two scores were then calculated for each student, one to assess self-efficacy related to science communication and Crosscutting Concepts and the second for general perception of science ability. Box and whisker plots were used to compare pre and post scores between the treatment and non-treatment groups. The survey scores were also evaluated to determine the percentage of students that identified they could provide examples of CCCs.

Earth Science Misconception Probes were used with both treatment and non-treatment groups during the unit on Geologic Time which took place near the mid-point in the treatment period and as part of the lessons on Glacial systems near the end of the treatment period. (Appendix G). Each probe was used at the beginning of the lesson sequence and revisited at the end just prior to unit assessments. Results of the initial responses to each probe were shared with each class the same day using a simple frequency table on the white board and used to prompt a discussion about background knowledge and formulate questions we might need to explore during our study. The treatment group used the CCC Thinking frame and CCC reference cards during this process. Final responses were evaluated using the Crosscutting Concept Application Rubric and writing was categorized as advanced, proficient, nearing proficient or novice.

(Appendix H). Initial use of the Geologic Time Misconception probe revealed a large number, over 50% of students left the reasoning blank. This limited the usefulness of comparing their reasoning when we revisited the probe after instruction. As a result, I modified the process and written instruction on the student worksheet prior to use of the Glacier Misconception Probe. Percent of students who improved the level of reasoning was calculated for both treatment and non-treatment groups.

Crosscutting Concept Application Questions were used to assess student recognition and familiarity with crosscutting concepts across different topics as well as specificity and detail of written explanations. Topic specific questions were written for each unit test administered during the treatment period. These content area assessments included Climate Change, Plate tectonics and Volcanic Systems, Glaciers and Surface water, and Geologic Time. One or more short answer question on each topic test or quiz targeted a specific CCC addressed in mini lesson received by the treatment group during that unit of study. For example, “What does the data show about stability and change in the system?” or “Use cause and effect to explain the relationship between greenhouse gases and global temperature. All students in both treatment and non-treatment groups received the same assessment questions. Crosscutting Concept Application Rubric was used to evaluate responses and writing was categorized as advanced, proficient, nearing proficient or novice. Frequency of accurate use was compared between treatment and non-treatment group as well as the distribution of writing level from novice to advanced. Writing samples from both the Earth Science Misconception Probes and Crosscutting Concept Application questions were used to assemble samples from the beginning, middle and end of the treatment period. Chi squared test was used to compare the distribution of writing

level between the treatment and non-treatment group both at the beginning of the study period and at the end using $p < .05$.

Crosscutting Concept Practice Tasks were completed using Science Interactive Notebooks with both treatment and non-treatment groups. Notebook entries were used to monitor student's incorporation and recognition of Crosscutting Concepts in their interactive notebooks and provide samples of their reasoning. This technique involved two parts and was completed at three points during the research period, once near the beginning, at the midpoint, and once near the end. Part 1. Students in both treatment and non-treatment group were asked to go back through their notebooks and locate a time they used a crosscutting concept in their notebook as part of notes, diagrams, observations, reflections etc. If they could not find a crosscutting concept, they were asked to identify a time they could have used a crosscutting concept and add a short explanation. On the same day I review the examples, and if a student misidentified, they were offered support to find an example and student success at CCC recognition was categorized as Independent or With Support. This initial review was completed as a formative assessment to provide immediate feedback to students and ensure each student had an appropriate Crosscutting Concept to work with for the next step. Part 2. Following initial recognition practice students were directed to complete an explanation using the following writing prompt model: Stability and Change is an effective way to explain Plate Tectonics because... The writing prompts were worded to reflect the specific CCC and topic and evaluated with the Crosscutting Concept Application Rubric. Descriptive statistics including relative frequency as a percentage and mode were used to compare the treatment and non-treatment groups for students who identified a CCC independently and compare the level of writing detail and specificity.

Science Learning Interviews were completed at the end of the treatment period to gather qualitative data related to student science self-efficacy, along with progress and understanding of crosscutting concepts (Appendix H). Interviews were conducted with small focus groups consisting of 2-3 students. Selection of focus groups was initiated by asking all students to complete a short google form identifying their willingness to participate in a small group interview with 1-2 other students. Treatment and Non-Treatment groups both ultimately included five male and five female students. From the list of willing participants, I selected students with a mix of achievement levels. Distributed among the ten students were two A students, three B students, three C students and two D students. Student comments were transcribed during the interviews and sorted to identify themes and summarize student's perceptions and opinions about the value of crosscutting concepts and self-efficacy related to science learning and particularly communication of science reasoning.

Students wrote Science Notebook Unit Reflections in their interactive notebooks to provide examples of CCC's in the context of recent content and individual perception of changes in confidence and participation in science class (Appendix B). Reflections were complete for each unit for a total of four written reflections during the treatment period. Responses were and evaluated for themes related to progress, science learning and frequency of clear examples of crosscutting concepts.

The methods and instruments for this research were designed to investigate the impact of direct instruction of Crosscutting Concepts in High School Earth Science. I attempted to address both validity and reliability in my research design. Validity is improved with consideration best practices for science instruction and keeping a clear focus on addressing my specific research questions. The Science Perspectives and Crosscutting Concepts Survey has not been

independently validated; however, the instrument was modeled after Student Attitudes Toward STEM (S-STEM) survey created by the Friday Institute for Educational Innovation (2012). This model informed my choice of a five-point scale, statements followed the direct format and were rewritten to be more focused on Crosscutting concepts and appropriate for my study. Standard school procedures for scheduling of students were key in the formation of my study groups and provided similar variability to previous years Earth Science classes. It is reasonable to suggest that future years would result in a similar population of students to work with and research. Reliability is also addressed by the incorporating the use of the Crosscutting Concept Application Rubric to evaluate all writing samples related to detail and specificity of explanation. Use of a rubric makes the assessment method clear and supports consistency of written sample scoring across classes, content, and timing during the treatment period.

CHAPTER FOUR

DATA ANALYSIS

Results

Data collection was carried out over four months using a mixed methods approach combining quantitative and qualitative methods. Earth Science students were divided into two groups non-treatment who received standard classroom instruction, and treatment in which direct instruction of Crosscutting Concepts was incorporated into the classwork and formative assessment. To investigate any impacts from this direct instruction changes to student recognition and familiarity with CCC's was monitored along with changes in proficiency of written reasoning and self-efficacy related to communicating in science.

Recognition and Familiarity with Crosscutting Concepts

Science Notebook Practice Tasks at the beginning of the study period showed 10% of the treatment group and 12% of the non-treatment group were able to independently identify an example of a Crosscutting Concept in their notebook work. The percentage of students able to identify an example of a Crosscutting Concept at the end of the study increased to 84% in the treatment group and 87% in the non-treatment group ($N=66$). Results from the Science Perspectives and Crosscutting Concept Survey showed a 29% increase in number of students that agreed they could give an example of a crosscutting concept in the treatment group as compared to a 9% decrease in the non-treatment group.

During student interviews one theme that emerged was the level of variation in examples of Crosscutting concepts. Non-treatment group students tended to provide one CCC applied to a specific topic with comments similar to one student who responded, "Like when we studied

volcanoes, we talked a lot about cause and effect.” Treatment group students had responses more like this student “Using system models was tied in a lot, with volcanic systems, or glaciers, or even with the whole global system thing we talked about at the beginning of the year.”

Treatment group students were more likely to provide a selection of examples where a CCC could be applied. The improvement of general familiarity was also shared by students in both groups, with one student sharing “I still struggle with specific examples, but I get the general ideas of how the concepts can work.” Another student compared to earlier in the year, “At the start of the year I didn’t really get it at all, but now I feel like get the overall idea.”

Detail and Specificity of Reasoning

Specificity and detail of reasoning was evaluated with Crosscutting Concept Application Questions. Results of this instrument from the beginning of the study showed 78% novice and nearing proficient in the treatment group compared to 73% in the non-treatment group ($N=71$). Nineteen percent of the treatment group had reasoning measured as proficient or better, while the non-treatment group showed 26% of students in this range (Figure 3).

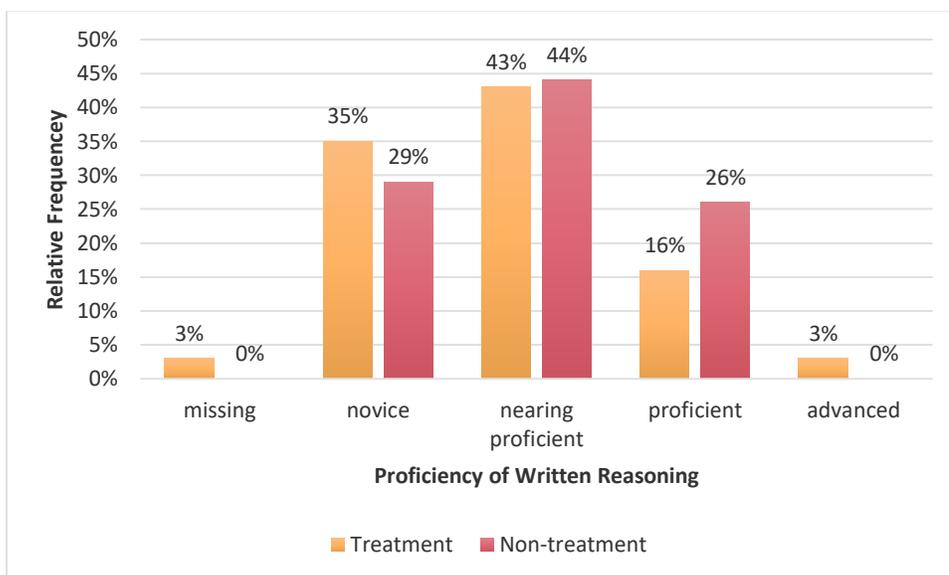


Figure 3. Distribution of written reasoning proficiency level as assessed with Crosscutting Concepts Application Questions at the beginning of the research period, ($N=71$).

Responses to Crosscutting Concept Application questions used to assess reasoning at the end of the study period revealed 17 students in the treatment group improved at least on level of proficiency compared to 7 students in the non-treatment group ($N=68$). Relative frequency calculations showed 43% of the treatment group had reasoning measured as proficient or better, while the non-treatment group had 18% of students in this range (Figure 4). While there were some indications of improvements, a Chi squared test showed that overall, there was not a significant difference in the reasoning proficiency of the treatment vs non-treatment group $\chi^2(1, N=71) = 1.2596, p = .738$.

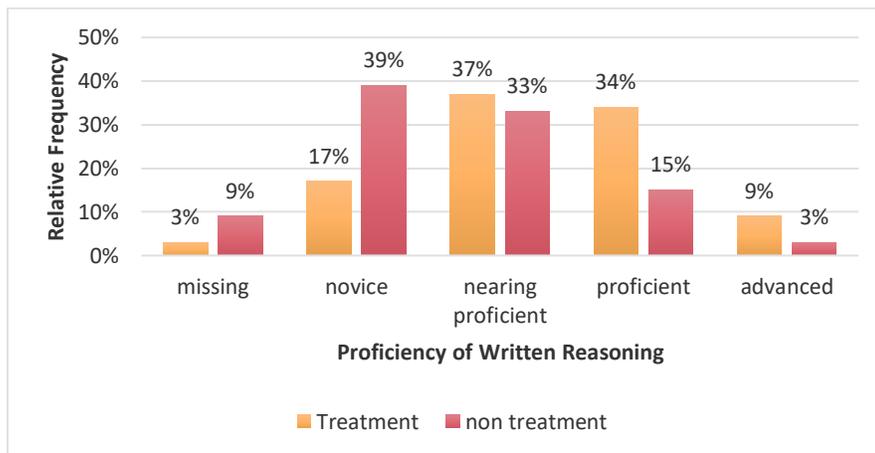


Figure 4. Distribution of proficiency level of written reasoning as assessed with Crosscutting Concepts Application Questions at the end of the research period, ($N=68$).

Science Notebook Practice Tasks provided samples of reasoning in a formative assessment. The specificity and detail of reasoning was ranked at the lowest level of novice for 42% in non-treatment group and 51% in the treatment group ($N=66$). Practice Tasks near the end of the study showed the non-treatment group had 44% of students in the novice category compared to 45% in the treatment group (Figure 5).

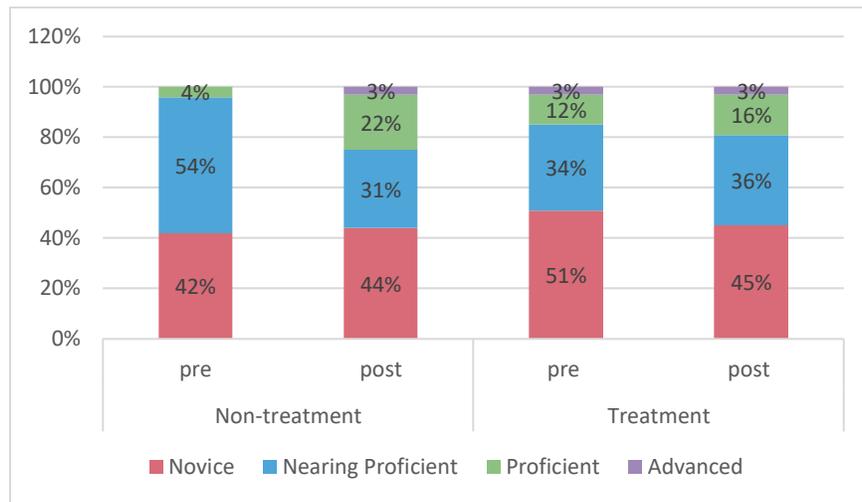


Figure 5. Change in relative frequency of written reasoning proficiency during practice tasks for non-treatment compared to treatment group, ($N=66$).

Anecdotal observations during formative tasks toward the end of the study period noted the non-Treatment group seemed to adhere closely to specific examples used in class as compared to the Treatment group where it was more likely to see a variety of examples. Treatment group students also had references referring to a CCC they may have used in a different context, for example one student wrote “melting of the glaciers is another effect and of climate change like the weather changes and rising oceans from before.” I observed students in the treatment group begin to rely on the specific tools we had used during formative tasks asking if they could use their CCC reference cards to help with examples.

Finally, an Earth Science Misconception Probe was used to compare improvement in the detail and specificity of reasoning. The relative percentage of students who initially provided novice or no reasoning was 43% in the treatment and 40% for the non-treatment group ($N= 64$). This assessment showed that from initial use of the probe to student responses when the same

probe was revisited, reasoning improved at least one proficiency level for 72% of students in the treatment group compared to 48% in the non-treatment group.

Self-efficacy Related to Science Reasoning and Communication

The Science Perspectives and Crosscutting Concepts Post Survey of the treatment group showed a decrease from 32% to 19% in students who felt anxious or stressed when trying to explain their thinking in science compared to the non-treatment group showed an increase from 26% to 30% ($N=62$) (Figure 6). In response to the statement “Using crosscutting concepts in my writing is confusing” the non-Treatment group remained constant with 22% of students agreeing as compared to the Treatment group that decreased from 45% to 35% (Figure 7).

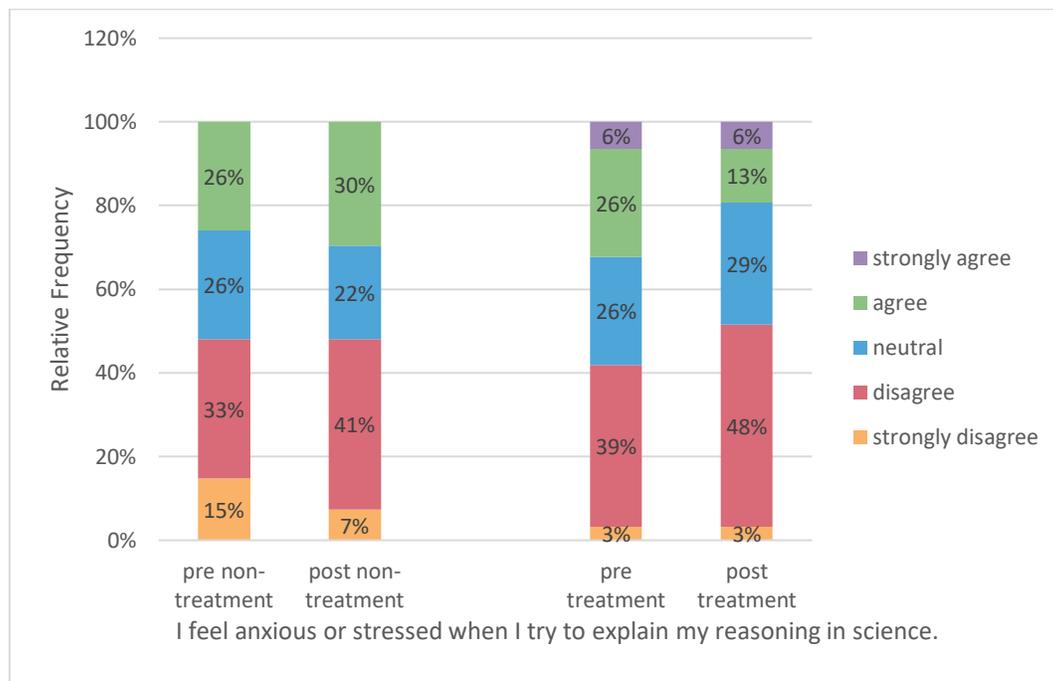


Figure 6. Stacked bar chart pre and post survey results of student anxiety when reasoning in treatment vs. non-treatment groups, ($N=62$).

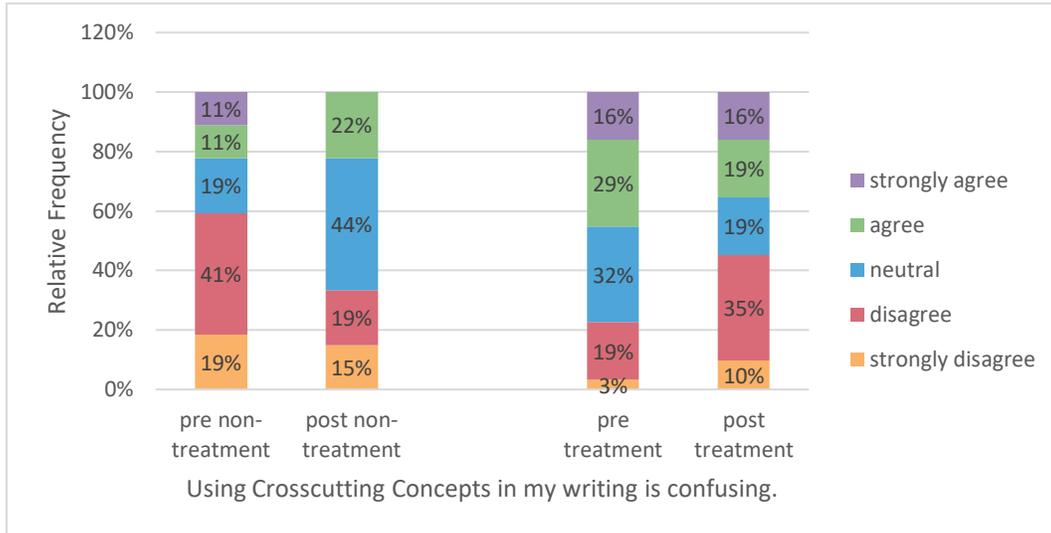


Figure 7. Stacked bar chart pre and post survey results of student who reported confusion when using Crosscutting Concepts in their reasoning in treatment vs. non-treatment groups, ($N=62$).

Student responses to the Science Perceptions and Crosscutting Concepts survey were summarized in a calculated self-efficacy score. The pre-survey median score for the non-Treatment group was 20 as compared to 18 for the treatment group.

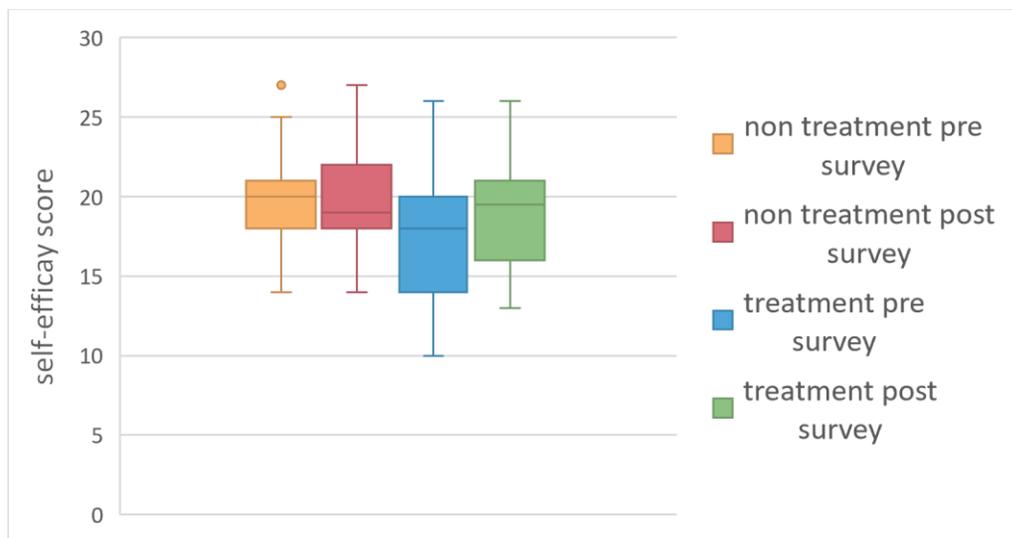


Figure 8. Box and whisker plot comparing the distribution of self-efficacy score for treatment and non-treatment group. Scores were derived from the Science Perspectives and Crosscutting Concept Pre and Post Survey, ($N=62$).

The post-survey median scores were 19 and 19.5 respectively (Figure 8). Both treatment and non-treatment group showed improvement in self-efficacy score over the course of the study. The minimum score in the non-treatment group remained constant while the treatment group displayed greater gains in first quartile and an increase minimum score from ten up to thirteen (Figure 8).

There were modest gains made by students in both groups related to self-efficacy and ability to communicate science reasoning, and this did appear to be greater overall for the treatment group in a few areas. When responding to the statement “Using CCC’s in my writing makes it easier to explain my thinking.” over 50% of students in the non-treatment group remained neutral and 30% of students agreed with the statement ($n=32$) (Figure 9).

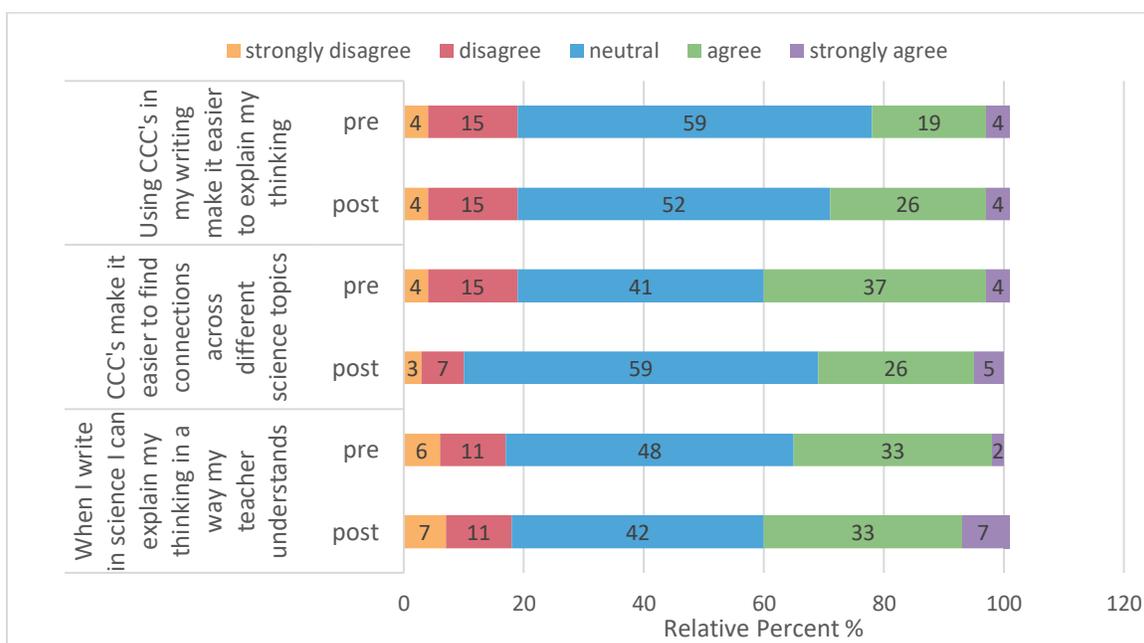


Figure 9. Stacked Bar Chart for non-treatment group shows change in student perceptions related to science communication and Crosscutting Concepts, ($n=32$).

Considering this same statement only 30% of the treatment group remained neutral with 38% agreeing that using CCC's in their writing made it easier to explain their thinking ($n=30$) (Figure 10). The treatment group also had a higher percentage of students that agreed they could explain their thinking in a way the teacher can understand with a post result of 46% that agreed or strongly agreed (Figure 10).

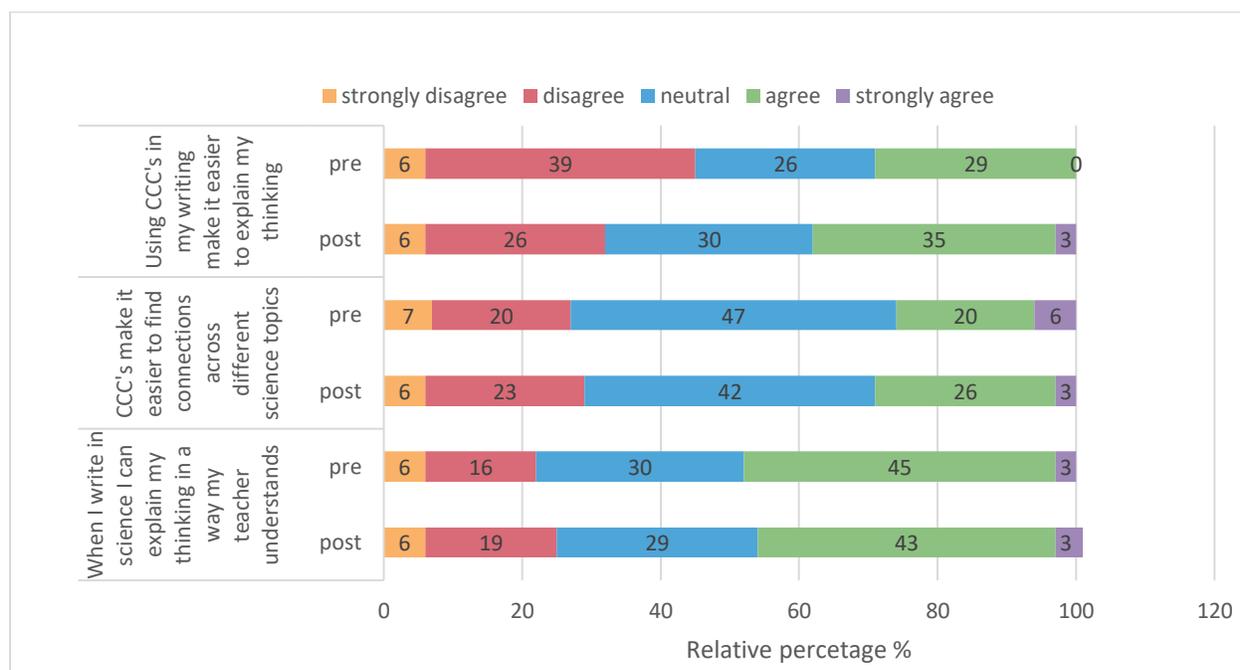


Figure 10. Stacked Bar Chart for treatment group shows change in student perceptions related to science communication and Crosscutting Concepts, ($n=30$).

When discussing their perspectives in focus group interviews there were some differing perspectives. Crosscutting concepts seemed to be viewed as just one more required step in the non-treatment group, often described as extra work, or just making things seem more complicated. Students in the treatment group were more likely to see the CCC's as a support tool as one student shared "I kinda liked the reminders that the concepts could fit in anywhere..." or "the Crosscutting Concepts gave me a place to start, when I remembered to think about it."

Many students felt like they had improved their science reasoning a little bit, but only a few students out of all of those interviewed said they felt confident in their science reasoning. The specific topic was very connected to their confidence, for example, one student commented “Yeah, I feel like I’m a little better at it, but it depends a lot on the topic ‘cause some just are easier than others.” Several students commented that they felt more confident with a specific topic, two student mentioned plate tectonics, two others mentioned climate, but did not extend their perception across all content. Anecdotally it was observed that students who were absent during direct instruction of a CCC had a higher level of confusion and less connection with classmates during discussion related to Crosscutting concepts.

CHAPTER FIVE

CLAIM EVIDENCE AND REASONING

During this study students in both treatment and non-treatment groups made progress related to Crosscutting Concepts in Earth Science. Quantitative data showed variation between the groups was often small, particularly regarding proficiency of reasoning on a standard based scale from novice to advanced and when comparing specificity and detail of reasoning. Qualitative observations support a shift in perceptions related to Crosscutting Concepts for students who received direct instruction. These students were more likely to apply one CCC to a variety of examples or topics and agree the Crosscutting Concepts make it easier to make connections and explain their thinking. In general, direct instruction helped incorporate the Crosscutting Concepts as part of the common language in Earth Science providing a framework of understandings that can apply to a variety of context. I found value in this strategy as it provided a consistent language for me to help structure student exploration while allowing students to develop a common vocabulary that incorporates their own understandings.

Claims From the Study

Student recognition and familiarity with Crosscutting Concepts increased in both treatment and non-treatment groups during the study. Differences in the groups appeared when looking at the confidence students expressed related to identifying Crosscutting Concepts, and variety of examples students provided. Students in the treatment group who received direct instruction related to CCC's included a noticeably wider variety of examples across different topics and reported an increase in confidence. The most references were connected to the individual CCC's that were address most frequently suggesting students were more confident

with these topics, an outcome similar to results from action research by Fitch (2019). I found it interesting that the post survey of the non-treatment group showed a decrease in the number of students who reported they could give an example of a Crosscutting Concept. I think it is possible that they initially did not understand what was really meant by a Crosscutting Concept and as a result overestimated their ability. Instruction over the course of the study clarified the CCC's but with little direct instruction students did not feel as confident giving examples as the treatment group reported. One challenge of using the two-group method for me as a teacher was keeping the direct instruction designed for the treatment group limited to just that group. It was easy to be consistent about the specific tools we used, but I found my verbal instructions and examples began to include more reference to the CCC's than I initially planned. As I got more comfortable with the use of Crosscutting Concepts they became a standard part of my teaching, and I had to make a concerted effort to limit the use. While in truth I was glad to see all students make progress in the skill, I think it is possible that there was more influence on the non-treatment group than intended.

Improvements to the detail and specificity of written reasoning varied widely when measured using CCC Application Questions. In a study with students in Australia in 2010, Venville identified medium to large gains following direct instruction of argumentation, however my results were more mixed. The non-treatment group had more proficient and nearing proficient responses early in the study, and the treatment group had more responses at this level during later assessments. It was difficult to determine if this was due to direct instruction of the CCC's or other variation in the understanding of the particular topics being assessed. The test setting of these questions seemed to make students more rushed when compared to written reasoning in a more formative setting. Students in the treatment group did show more

improvement in the Science Notebook Practice tasks with a larger portion of students improving their reasoning from novice compared to the non-treatment students. Unlike Poland (2018) I did not see noticeable increase in student use of CCC's with out specific prompting, but I did find similar results in interviews supporting an increase in student confidence following direct instruction in the Crosscutting Concepts.

Throughout the study there was a large percentage of student that remained in the novice level of reasoning with the most notable exception being during use of the Misconception Probe. This tool showed the largest increase in proficiency from initial introduction to the revisiting of the probe. This activity took place near the end of the study and students at this point had been exposed to Crosscutting Concepts and direct instruction tools multiple times. However, I did only end up with data from one misconception probe, and the narrow focus of the glacier probe might have contributed to student progress compared to more general or student driven practice in other units. The material was also covered, and the probe revisited over a shorter time frame compared with other formative science notebook tasks. Overall, my quantitative data showed mixed results related to gains in specificity and detail of reasoning, but I did not see negative impacts of my direct instruction.

Self-efficacy proved to be challenging to measure which was not too surprising but did emphasize that there are many factors that influence how a student feels about their learning. Surveys with the treatment group showed a decrease in students who found the Crosscutting Concepts confusing, and an increase in the number of students who felt using Crosscutting Concepts made it easier to find connections and explain their thinking. This is similar to the pattern seen with seventh grade students by Poland (2018) identifying improved confidence in writing following instruction with CCC's. While there did appear to be some gains in this area of

research, I am not sure that a single pre and post survey gives the best picture. Student interviews provided a more holistic picture and gave students a chance to elaborate on how they were feeling. The indifference for the Crosscutting Concepts that stood out in the non-treatment group speaks to the importance of direct instruction related to these concepts. They were familiar with the terms from class posters and simple examples, but in general did not see much value in using CCC's to study or explain and ideas. This seemed to directly address the question posed by Fick (2019) related to the improvement of learning with intentional foregrounding of the Crosscutting Concepts. When comparing differences between students, the treatment group who received direct instruction prior to exploration of different content certainly expressed awareness of value in the Crosscutting Concepts even if they did not always feel confident that they understood the details.

Value of the Study And Considerations for Future Research

Crosscutting Concepts were incorporated as a rich part of the classroom setting during this study. Cooper (2020) suggested that CCC's can act as bridges across content, can be used as tools or lenses to focus investigations, and help build a level starting point for learning. I observed all these roles related to the use of Crosscutting Concepts, and the more we used them the more options I realized. Of course, this was not a flawless transition, and some students were more successful than others at grasping the power of CCC's in science. I found that Crosscutting Concepts also played a role in many of the Science Practices, and as my students became more familiar with the Crosscutting Concepts their incorporation emerged as a norm of scientific investigation. Students began to see how CCC's fit in to our learning culture. I particularly noticed a sense of common ground the more the CCC's were incorporated, and students realized

there were a lot of right answers. As suggested by Frost (2022) the familiarity with Crosscutting Concepts allowed students to draw on their own experience and observations in a new context. When we worked with a particular CCC my students got more and more comfortable sharing how they saw things fit or connect, and less nervous about having a response different than their peers. This building of common language was very valuable for me as an instructor, and I feel has big implications for equitable learning and building tools to meet students where they are in their learning.

These initial observations of progress and some gains in recognition and reasoning lead me to numerous additional questions. The most direct extension for my teaching is investigation into the efficacy of different types of direct instruction. I used, Crosscutting Concept reference cards, CCC Thinking Frame, and Mini lessons with graphic organizers during this study. I think there is much to be learned about the sequence these techniques are introduced, student preferences and other possible options for teaching Crosscutting Concepts in context of different science content. I think it is also important to note that direct instruction does not suggest that the Crosscutting Concepts should be taught in isolation but incorporated as an intentional aspect of learning core ideas. My study focused on impacts of direct instruction over a relatively short window of time at a single high school grade level. In researching my conceptual framework, I found numerous resources addressing the role and potential for Crosscutting Concepts, but surprisingly little actual research with students. A collaboration across grade bands could include research into the impact of Crosscutting Concepts when introduced in early grades and continued through upper grades across different science content. The organization and scope of this project would be daunting but could provide valuable insight into the role of the CCC's in supporting

scientific literacy. There is still much to be learned about the long-term impact of Crosscutting Concepts as the third dimension the Next Generation Science Standards.

Impact of Action Research

I always enjoy using new ideas and techniques and endeavor to be professional and thorough in my consideration of possible benefits and outcomes. Engaging in action research this year fostered a focused and intentional approach in the use of new teaching methods that I had not experienced in the past. Throughout this school year I was appreciative of my focused research questions and relied on that thread through my planning. This clarified to me the potential that annual goals and clear questions could have on my teaching going forward. This research also reinforced the value of the Crosscutting Concepts for me as my familiarity grew through my efforts to support my students. I felt that as my own understanding grew, I was able to see an increasing number of possibilities for incorporation of Crosscutting Concepts into my teaching. I feel validated in my perspective about the potential for Crosscutting Concepts to provide a common language that will honor students' own knowledge and help foster a culture of lifelong learning and support the goal of improving scientific literacy. I watched as students began to rely on tools I introduced and supported each other with small comments about where to find the CCC's on posters and notebook guides as they worked through practice tasks. Like any aspect of teaching this one strategy will not solve all issues, but I feel optimistic that it will help students see progress in their learning and possibly open lines of thinking and perspective about science that they would not otherwise experience. This research has certainly clarified possibilities for me, and I look forward to implementing and sharing what I have learned.

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APPENDICES

APPENDIX A

IRB RESEARCH EXEMPTION

Dear Libby,

Thank you for your application. This email acknowledges receipt of the request for IRB Review and serves as the Approval Letter for your research. Your new **IRB Exempt Protocol # is LZ122121-EX**.

Study Title: Cross-cutting Concepts as a Language for Reasoning and Sensemaking in High School Earth Science

As the PI, it is your responsibility to facilitate subject understanding by informing subjects of all aspects of the project, providing an opportunity to ask questions, and describing risks and benefits of participation. Submit any new changes to the research protocol to the IRB via [Amendment Form](#) prior to implementing.

The research described in your submission is exempt from the requirement of additional review by the Institutional Review Board in accordance with 45 CFR 690.104(d). The specific paragraph which applies to your research is:

(1) Research, conducted in established or commonly accepted educational settings, that specifically involves normal educational practices that are not likely to adversely impact students' opportunity to learn required educational content or the assessment of educators who provide instruction. This includes most research on regular and special education instructional strategies, and research on the effectiveness of or the comparison among instructional techniques, curricula, or classroom management methods.

Thank you,

Kelly Beiswanger

IRB Administrator & Program Manager
Office of Research Compliance
Hamilton Hall 114
Montana State University
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<https://www.montana.edu/orc/irb>

APPENDIX B

INTERACTIVE SCIENCE NOTEBOOK STUDENT RESOURCES

CER Writing Guide

Your goal is to write an explanation using precise and accurate scientific language so others can understand it. You want to explain your thinking to help share your knowledge.

<p>Claim: an assertion or conclusion, (often answers and original question).</p>	
<p>Evidence: Scientific data that supports the claim. Can come from investigations, observations, reading material, archived data or other sources.</p>	
<p>Reasoning: Explain the connection between the claim and evidence. Justification for how the data works as evidence to support the claim. Can use language of Crosscutting Concepts.</p>	

Notebook Expectations/Rubric

NOTEBOOK:

- Note taking captures the essential information and concepts
- uses diagrams, labels, charts and sketches to add clarity and detail
- has all expected components, dates, titles, unit guides, tabs
- organization makes it possible to find information as needed

In addition to regular classwork in your notebook, reflections will be part of our science work this year. Thinking about information covered, skills practiced, connections you notice and questions you have, is an effective way to evaluate your progress in science.

These are the required standards for each reflection

- **CORE IDEAS:** summarize the key ideas in the content we covered. What connections did you make/notice to previous work or personal experience? What questions have developed or been left unanswered?
- **CROSS CUTTING CONCEPTS (CCC):** describe how one CCC was helpful to your understanding, made a connection or is otherwise related to the content
- **ENGAGEMENT:** comment on your participation, engagement and attitude. Did you consistently engage with tasks and work with classmates and teacher with a positive outlook and honest effort? What made your engagement as a student easier or more difficult lately?

Self Grade: Refer to your Notebook expectations above and give a rating for your notebook work since your last reflection.

- _____ All standards met and exceeded (100%). Notebook in general goes above basic expectations, has in depth reflection, color, outside research and more.
- _____ All standards met (95%). Notebook meets expectations and topics for reflection have been thoroughly addressed.
- _____ One standard not met (88%)
- _____ Two standards not met (80%)
- _____ Three standards not met (70%)
- _____ Four or more standards not met (50%)

APPENDIX C

CROSSCUTTING CONCEPT STUDENT REFERENCE CARDS

Crosscutting Concepts

These concepts help provide students with an organizational framework for connecting knowledge from the various disciplines into a coherent and scientifically based view of the world.

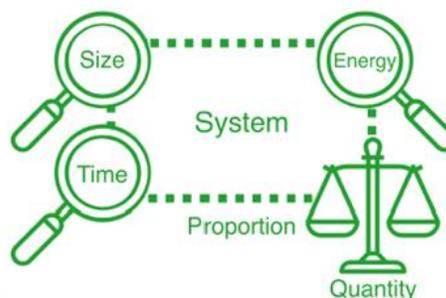
- Patterns
- Cause and Effect: Mechanism and Explanation
- Scale, Proportion, and Quantity
- Systems and System Models
- Energy and Matter: Flows, Cycles, and Conservation
- Structure and Function
- Stability and Change

Scale, Proportion, and Quantity

It is critical to recognize what is relevant at different size, time, and energy scales, and to recognize proportional relationships between different quantities as scales change.

Framing Questions

- What aspects of the system may be relevant at different time, size, and energy scales?
- How do different quantities vary at different scales?
- What measurements could be made to describe the system more precisely?
- What proportional relationships can be observed?

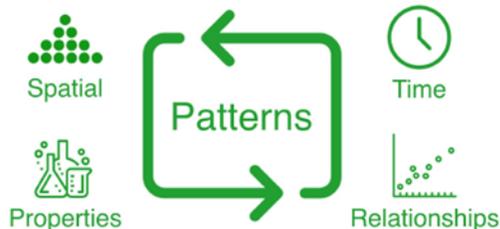


Patterns

Observed patterns of forms and events guide organization and classification, and they prompt questions about relationships and the factors that influence them.

Framing Questions

- What structures or shapes are found in the phenomenon or system after careful observation?
- What cycles or events repeat over time?
- How could these patterns be represented?
- How could patterns be used to classify or organize objects and events?
- What causal relationships are found in the data?

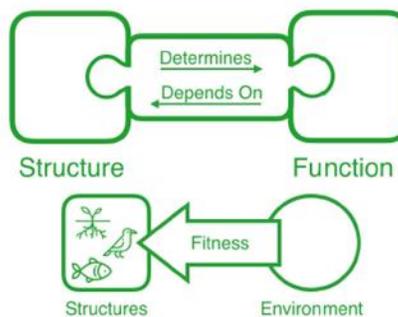


Structure and Function

The way an object is shaped or structured determines many of its properties and functions.

Framing Questions

- What shapes or structures are observed in the system at this scale?
- What roles do these structures play in the functioning of the system?
- How do the structures support the functions?
- How does the environment affect the fitness of organisms with specific structures?

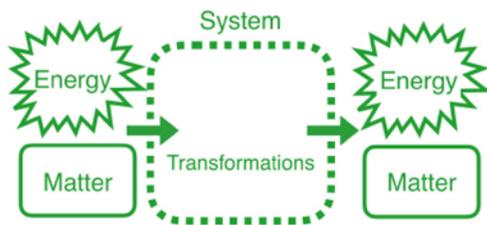


Energy and Matter

Tracking energy and matter flows, into, out of, and within systems.

Framing Questions

- What matter flows into, out of, and within the system?
- What physical and chemical changes occur in the system?
- What transformations of energy are important in the system?
- How does the flow of energy drive the movement of matter in the system?
- How are energy and matter conserved in the system?



Stability and Change

Conditions that affect stability and factors that control rates of change are critical elements to consider and understand in natural systems.

Framing Questions

- Under what range of conditions does the system operate effectively?
- What changes in conditions cause changes in its stable operation?
- What changes in conditions could cause the system to become unstable or fail?
- What feedback loops in the operation of the system enhance its range of stable operations?

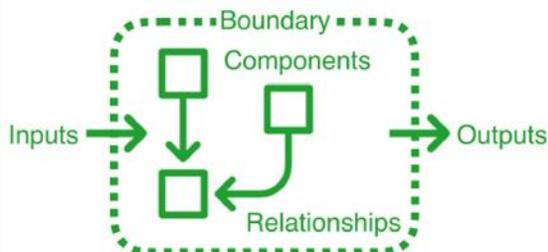


Systems and System Models

A system is an organized group of related objects or components. Models can be used for understanding and predicting the behavior of systems.

Framing Questions

- What is included in the system? What is external?
- What are the components of the system and how are they related?
- What are the inputs and outputs of the system?
- What predictions can be made from a system model?
- What are the limits of the system model?

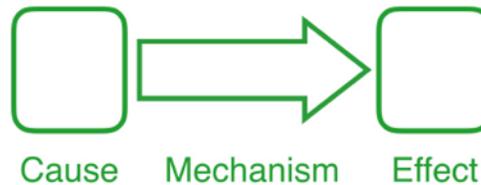


Cause and Effect

Events have causes, sometimes simple, sometimes multifaceted. Correlation does not imply causation.

Framing Questions

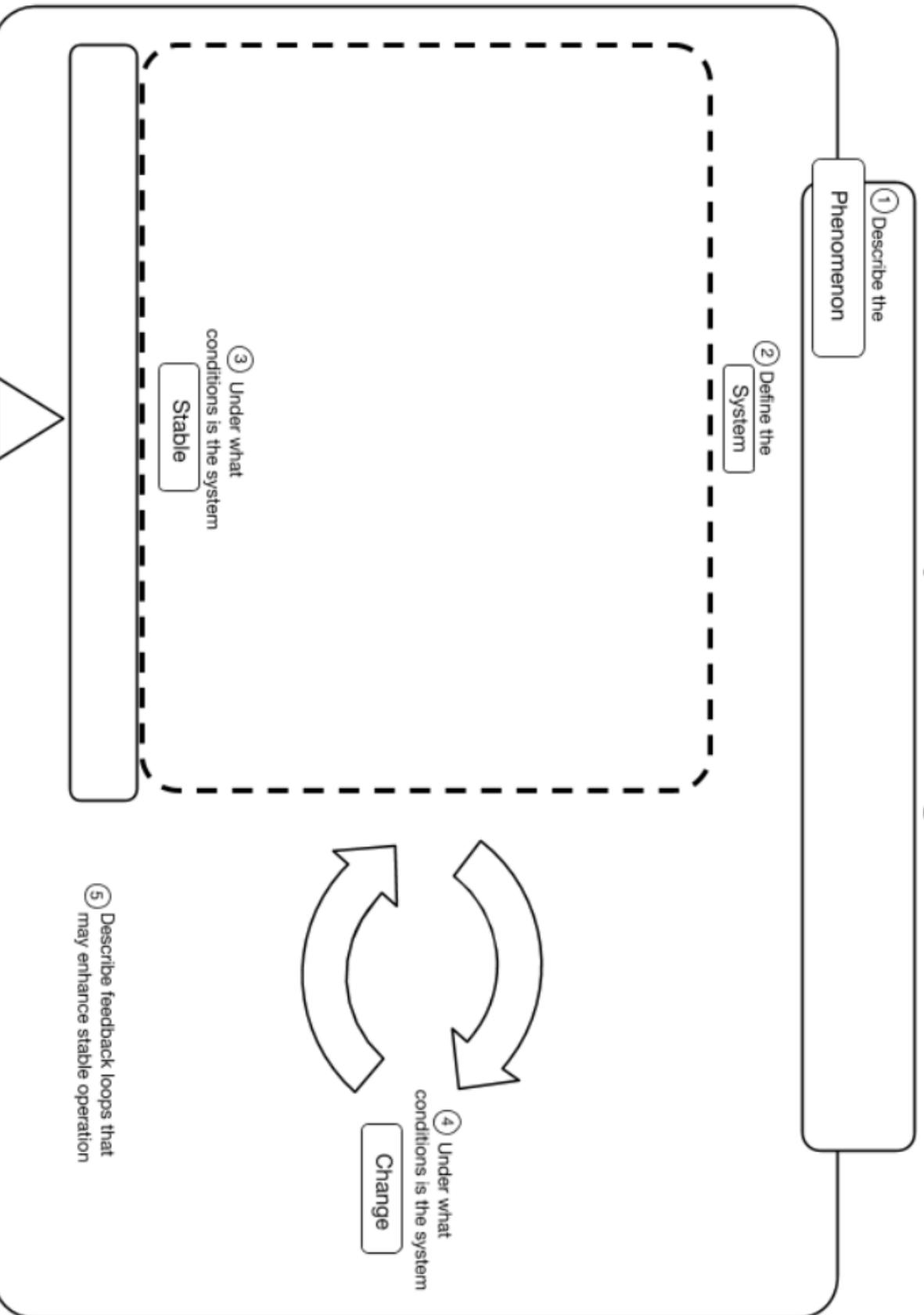
- What relationships between events or patterns can be observed in the phenomenon or system?
- How can these relationships be explained?
- Are any of these relationships cause and effect?
- What evidence supports a cause and effect relationship?
- What further investigations would help determine if these relationships are cause and effect?



APPENDIX D

STABILITY AND CHANGE MINI LESSON ORGANIZER

Stability and Change



APPENDIX E

CROSSCUTTING CONCEPT THINKING FRAME

Phenomenon/Investigation:	Crosscutting Concept: Patterns Cause and Effect Energy and Matter System Model Scale, Proportion, Quantity Stability and Change Structure and Function
What do you notice...? What do you know?	What do you wonder...? What do you need to know?

APPENDIX F

SCIENCE PERCEPTIONS AND CROSSCUTTING CONCEPTS SURVEY

Student Survey #1

Please indicate your agreement with each statement. Your answers will be kept strictly confidential and will not be identified by name. Your participation in this research is voluntary and participation or non-participation will not impact you grade or class standing in anyway.

Circle the number according to the following 5 point scale.

strongly disagree disagree Neutral agree strongly agree
 1 2 3 4 5

1. I consider myself a science person	1	2	3	4	5
2. I feel anxious or stressed when I try to explain my thinking in science.	1	2	3	4	5
3. Using crosscutting concepts in my writing makes it easier to explain my thinking.	1	2	3	4	5
4. When I don't understand something in science it makes me curious to learn more about it.	1	2	3	4	5
5. Crosscutting concepts make it easy to find connections across different science topics.	1	2	3	4	5
6. My teachers believe I can do well in science courses.	1	2	3	4	5
7. Science is my weakest subject.	1	2	3	4	5
8. Using cross cutting concepts in my writing is confusing	1	2	3	4	5
9. I can give an example of a crosscutting concept.	1	2	3	4	5
10. When I write in science, I can explain my reasoning in a way my teacher understands.	1	2	3	4	5
11. Science is harder for me than for my classmates.	1	2	3	4	5
12. I am confident that I can get a good grade in science.	1	2	3	4	5

Gender: _____ Do you plan to take a science class next year? Yes / No / Maybe

Plans following High School _____

APPENDIX G

CROSSCUTTING CONCEPTS APPLICATION REASONING RUBRIC

Used to address sub questions

- a. *To what extent does the direct instruction of crosscutting concepts impact student ability to recognize the crosscutting concepts across different contexts or topics?*
- b. *To what extent does direct instruction of crosscutting concepts impact the detail and specificity of reasoning in CER writing format?*

Student writing samples were obtained through use of misconception probes and unit assessments

Advanced	Proficient	Nearing Proficient	Novice	Missing
4	3	2	1	0
Appropriate CCC was used with detail and specificity to accurately answer the question.	Appropriate CCC was referenced in a basic context to answer the question	Appropriate CCC suggested or implied. Answer is general	Explanation was attempted but is very vague and/or not well connected to a CCC	Response was left blank

APPENDIX H

SCIENCE LEARNING INTERVIEW QUESTIONS

Prior to interviews all students are informed and provided a written statement stating: Your answers will be kept strictly confidential and will not be identified by name. Your participation in this research is voluntary and participation or non-participation will not impact you grade or class standing in anyway.

Question or portions of questions in *Italics* will be used to further prompt students if necessary.

1. Do you consider yourself a science person? Has that perception changed over the course of the year? *Why do you think that is?*
2. We have been using different learning strategies during our study of Earth Science this year. What do you feel has been most helpful to you?
3. How confident do you feel now in your ability to explain your thinking or reasoning in earth science? (Visual scale below was used as reference for this question) Has that changed since the start of Earth Science? *In what way?*
4. We have used a variety of cross cutting concepts during our study of Earth Science this year. What are these cross cutting concepts? *Give me as many examples as you can think of.*
5. Do you agree with the idea that crosscutting concepts can apply or fit into the study many topics? *Why or why not? Can you give an example?*
6. Was it helpful to include crosscutting concepts in class this year? *In what way? Can you elaborate, or tell me more?*
7. Do you think these crosscutting concepts would be helpful in other classes? How about outside of school?

Visual confidence scale

