Creative Problem Solving in the Classroom:

Metacognitive Strategy Instruction for Creative Cognitive Construction

by

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ABSTRACT

As schools continue to focus on outcome-based instructional practices, less emphasis is placed on the creativity and reasoning necessary for students to become effective critical thinkers. As a result, students struggle to demonstrate creative problem-solving skills in the classroom. This study examines how the facilitation of an instructional problem-solving intervention, Creative Cognitive Process Instruction (CCPI), can foster creativity, improve student metacognitive regulation, and support students in developing problem solving strategies. Participants included (n = 33) 7th grade science students in a California public middle school.

Mixed methods were used to assess how and to what extent CCPI changed students' metacognitive regulation and attitudes and approaches to creative problem solving. Outcomes from this study indicate that a structured approach to problem solving along with creative and metacognitive instruction and a scaffolded support system had a positive impact on students' creative problem-solving perceptions and abilities. Notably, students demonstrated an attitudinal shift from “getting the work done” to “getting the work done well”, corresponding with a focus on understanding the problem followed by an improvement in solution synthesis. Students also demonstrated improvement in comprehension and metacognitive planning abilities, divergent thinking, their perception of science, and their self-perceived competency in science.

This research may suggest how to enhance classroom practices to facilitate a more creative and engaged problem-solving mindset, foster the implementation of creative problem-solving strategies in the classroom, and support existing theories of the intersectionality of metacognition and creative problem solving.

DEDICATION

I dedicate this dissertation to my family, for their love and support in this and all other endeavors.

To my mom, Samar, my greatest example of resilience, fortitude, and courage. Thank you for standing by me, for your confidence in me, for nurturing my creativity, and embracing my unconventional ideas. Through your dedication, tireless effort, and commitment, you have taught me to never give up, and have shown me that anything is possible. I am proud to have such an incredible example of unwavering strength and grace to look up to.

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You have all reinforced in me the value of working hard, being kind, and staying humble, doing things the right way, not the easy way, and standing by my values and integrity. I love you all more than words can express.

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UNDERSTAND: LEADERSHIP CONTEXT AND PURPOSE OF STUDY

As schools continue to stress the teaching of objectively measurable behaviors, students struggle to learn in meaningful ways (Mayer, 1987, p. 327-8). When educators think about the skills and experiences that would have the most profound impact on their students' abilities to engage in metacognitive regulation and creative ideation, the ability to problem solve rises to the top. Students must be able to face challenges and overcome them, large or small, inside the classroom and out. To do that, they must develop confidence and participate in the practice necessary to engage with their own thoughts and complex ideas. When it comes to the classroom, “teachers aren’t there to solve problems for the students, but to support them in solving the problems themselves” (Mills & Kim, 2017). Therefore, equipping students with the skills they need to thrive as problem solvers is essential.

This study examines the facilitation of a problem-solving process that fosters creativity, improves student metacognitive regulation, and supports students in developing the strategies required to be successful problem solvers.

National Context

While the challenges faced by a teacher and their students inside a classroom may feel localized and personal, they often represent a larger truth shared across classrooms in schools all over the nation and globally. When one challenge is faced by so many, it seems necessary to search for solutions.

Emphasis on Creative Problem Solving

A 2018 global study of 1600 educators and 400 policymakers conducted by the Adobe software company found that educators in the United States (U.S.) were the most likely to feel that there is not enough emphasis placed on creative problem solving in school curricula, and most likely to feel that current educational policies were hurting educators' abilities to nurture creative problem solving. Although this study showed 99% of US educators and 99% of US policymakers surveyed agree that creative problem solving is important for students to learn in school, it is not often the norm to find arts-infused instruction in Science, Technology, Engineering, and Math (STEM) disciplines within the U.S. educational system (Henriksen, 2014). Of those surveyed, 84% of educators and 68% of policymakers agreed there is not enough emphasis on creative problem solving in today's curricula (Adobe, 2018).

We live in a rapidly evolving world, full of complex problems. Real world problem solving is multifaceted and requires a breadth of knowledge, experience, and creativity. The complex problems and issues of today require 21st century scientific thinkers who are also creative thinkers that go beyond disciplinary content and work between disciplines (Mishra, et al., 2013; The Partnership for 21st Century Skills, 2007 as cited in Henriksen, 2014). This idea provides a basis of support for the importance of teaching creativity and problem solving within the realm of critical thinking across all curricular subject matter. While global research shows that the jobs of tomorrow will demand creative problem-solving skills (Adobe, 2018),

> in schools today there are tasks, but no value is placed on creative solutions - only on the fact that the tasks are executed correctly. Creative problem solving and

> more independent work would have to be integrated into the curriculum for all subjects at an early stage (Adobe, 2018)

to better prepare students for future demands. Thus, programs that introduce and stress interdisciplinary curriculum, ideas, and activities would be an ideal ground for this type of thinking and skill to be developed and practiced. When looking specifically at the distinctions commonly made between the creativity associated with the arts, versus the more traditionally rational and logic based STEM disciplines, it has been noted "the future of innovative thinking in STEM disciplines relies on breaking down the distinction between disciplines traditionally seen as 'creative' like the arts or music, and STEM disciplines traditionally seen as more rigid or logical-mathematical" (Catterall, 2002 as cited in Henriksen, 2014, p. 1).

The Adobe (2018) study found that of all countries surveyed, US educators were also the most frustrated with current educational policies and standardized testing requirements, with 80% of US educators believing current policies hurt their abilities to nurture creative problem solving. Unfortunately, "educational policies often make it difficult for teachers to teach this way without deviating from standards-driven curriculum" (Fusarelli, 2004 as cited in Henriksen, 2014, p. 1). While educational reform in the US continues to be an ongoing process, it is clear there is a long way to go before the structure and opportunity provided through K-12 education most accurately supports and encourages students to be critical and creative thinkers inside and outside of the classroom.

Next Generation Science Standards (NGSS)

Today's educators face the additional challenge of preparing students for standardized assessments, while still adding creativity to the curriculum, sparking curiosity, and inspiring student motivation through their lessons and in-class assessments (Longo, 2010). The question they face is how to accomplish this in a way that meets the critical and creative needs of the students in meaningful ways in the classroom, while also developing the necessary foundation and skills students require to best demonstrate their knowledge and abilities when assessed. According to Longo (2010), when educators generate thoughtful, real-world, and metacognitive opportunities for students in the classroom, students are more likely to retain what they learn, and connect classroom learning to standardized assessments. Thus, the notion of "teaching to the test" must go out the window and be replaced with a mindset of growth and opportunity that builds a foundation for much more.

To eliminate the practice of "teaching to the test" (National Science Teaching Association [NSTA], 2014c), over the last decade in the US, there has been a shift from direct instruction approaches to student-led inquiry models with the gradual adoption and implementation of the Next Generation Science Standards (NGSS). The groundwork for the NGSS was laid by A Framework for K-12 Science Education (The Framework), which is the foundational report produced by the National Research Council (NRC) (https://nextgenscience.org). The NGSS focus learning on solving problems by creating opportunities to shift toward meaningful problem-driven instruction, supporting students in explaining phenomena, and designing solutions to problems (NextGenScience, 2021). By using problems to drive learning, students become intrinsically motivated to learn science and engineering ideas to find solutions to those problems (NextGenScience, 2021). Although the phenomena driven-approaches laid out by The Framework for K-12 Science Education are becoming more widespread, there are fewer examples of problem driven learning that align to the vision of both The Framework and the NGSS (NextGenScience, 2021).

While it was found that students could often answer questions about topics specifically covered in class, they struggled to translate that knowledge in applied situations (NSTA, 2014c). The NGSS attempt to bridge this disconnect by combining knowledge with practice in teaching students how to develop and evaluate ideas. Rather than solely listing the content students should know and the processes they should be able to do, the NGSS provide a set of performance expectations that integrate Science and Engineering Practices (SEPs), Disciplinary Core Ideas (DCIs), and Crosscutting Concepts (CCCs) (NSTA, 2014b). The SEPs describe behaviors students engage with as they investigate the natural world and design solutions (California Assessment of Student Performance and Progress [CAASPP], 2022).

The eight SEPs The Framework identifies are:

1. Asking questions and defining problems
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations and designing solutions
7. Engaging in argument from evidence

8. Obtaining, evaluating, and communicating information (NextGenScience, 2013)

The expectations laid out by these SEPs are indicative of those you would find in most problem-solving processes, falling within the framework of identifying a problem, considering approaches, and generating reasonable solutions.

In 2013, the State Board of Education (SBE) adopted the Next Generation Science Standards for California Public Schools, Kindergarten through Grade Twelve (CA NGSS) (California Department of Education [CDE], 2022b), along a test aligned with these standards, the California Science Test (CAST) (CDE, 2022a). The CAST is administered to students in California three times, first in 5th grade, again in 8th grade, and one final time in 11th grade. Every item scored on the CAST is aligned with NGSS performance expectations, each with corresponding SEPs.

Over the last 5 years, the CAST has been fully administered three times, first during the 2018-2019 school year, again during the 2021-2022 school year, and last during the 2022-2023 school year. The CAST was not administered during the 2019-2020 school year and not fully administered during the 2020-2021 school year due to the COVID-19 pandemic. During the 2018-2019 school year, 30.84% of 462,504 8th grade California students met or exceeded the standard for science on this examination, dropping to 29.20% of 436,594 students meeting or exceeding the standard during the 2021-2022 school year, and further dropping to 28.76% of 420,307 students meeting or exceeding the standard during the 2022-2023 school year (CAASPP, n.d.).

As of 2022, 20 states and the District of Columbia (representing over 36% of U.S. students) have adopted NGSS, while 24 more states (representing 35% of U.S. students) have developed standards based on this framework (NSTA, 2014a). While the NGSS implicitly include problem-solving expectations through alignment with the SEPs, they do not explicitly outline the facilitation of creative problem solving in the classroom. Through analysis of CAST test scores, the concerns of US educators, and evaluation of the NGSS aligned performance expectations themselves, it is therefore reasonable that greater emphasis on creative problem-solving instruction in the classroom would positively impact students.

The NGSS were designed to place an emphasis on investigation and critical thinking, which requires students to develop a solid understanding of core concepts by using critical thinking skills to apply them. According to nextgenscience.org (n.d.), "these standards give local educators the flexibility to design classroom learning experiences that stimulate students' interests in science and prepare them for college, careers, and citizenship." The issue here lies in the idea that the NGSS attempt to remove teachers from an active role, and place them in a passive one, while students have not yet been equipped to move into the active role themselves. This puts teachers in a unique situation where they are expected to be hands-off and give students the room to *get there*, while teaching students who have not previously had to think critically in this way to *get there* themselves.

In the large context, this illustrates the fact that not only is there a need to teach students how to put their knowledge and ideas together to creatively problem solve, but there is also a need to look at the framework teachers provide in their classrooms and lessons to ensure that students understand how to do so and are given the room to do so. If the intention of NGSS is to help students explore and apply content, then teachers need to be prepared to pedagogically meet these goals (Zangori & Pinnow, 2019). The curriculum being taught has been informed by decades of research, and provides the "what" of learning, while the sciences, specifically, provide ways in which the "how" of teaching can be improved, by making content applicable, useful, and relevant (Zangori & Pinnow, 2019). Science educators can use an inquiry approach to combine content and skill to prepare students for the realities of standardized testing, while maintaining creativity in the classroom (Longo, 2010). Thus, to successfully implement the NGSS into their classrooms, teachers need to establish instructional methods and discourse norms that help students learn how to approach problem solving and innovate solutions to the problems and concepts they are presented with.

Local Context

At the time of this study, I worked as a middle school science teacher in an arts-based academy within a large middle school in a PreK-12 school district in California. The district spanned urban and suburban areas and served over 500,000 students. In relation to the science curriculum, in 2016 the district selected the integrated model laid out by the California Science Framework (2016) to replace the grade 6-8 core science courses, with full implementation of the NGSS starting in the 2018-2019 school year when NGSS specific instructional material became available. Like the statewide administration of the exam, the district administered the CAST to students three times in the last 5 years, first during the 2018-2019 school year, again during the 2021-2022 school year upon returning to in person instruction after the virtual instruction due to the COVID-19 pandemic, and last during the 2022-2023 school year. District performance for 8th graders on this exam fell well below that of the state performance, with just

23.11% of 34,153 8th grade students meeting or exceeding the standard for science on this exam during the 2018-2019 school year, declining to 22.03% of 30,751 8th grade students meeting or exceeding the same standard during the 2021-2022 school year, and further declining to 20.93% of 29,235 8th grade students meeting or exceeding this standard during the 2022-2023 school year (CAASPP, n.d).

Another alarming trend appears when following the same group of students between grade levels, with data showing student performance on the CAST decreases for students who were first tested in 5th grade, and again in 8th grade, as well as for those who were first tested in 8th grade, and again in 11th grade. 24.28% of 5th grade students tested in the 2018-2019 school year met or exceeded the standard for science. When these students were tested again in 8th grade during the 2021-2022 school year, this number fell to 22.03%. Similarly, 23.11% of 8th grade students tested in the 2018-2019 school year met or exceeded the standard for science, and when these students were again tested as 11th graders during the 2021-2022 school year, this number had dropped to 20.85% (CAASPP, n.d.).

Since the CAST is designed to assess students against the same SEPs that construct the NGSS framework, these lower scores seem indicative of a deficit in the kind of learning where these SEPs are involved and stress the importance of better addressing them in the classroom. Since the expectations laid out by these SEPs are aligned with problem-solving processes, these scores illustrate a compelling argument for the need to improve student proficiency with problem solving in the classroom. The data points that exist in relation to student achievement on the CAASPP happen to fall on opposite sides of a global pandemic, which is likely a contributing factor to the decrease in scores across the board. However, this makes it even more necessary to provide students with strong foundational understanding and experience with problem solving, so they have a better chance of retaining and utilizing it, even in the face of adverse challenges. Looking at the achievement scores pre-pandemic, less than one-fourth of students in the district were meeting or exceeding science standards to begin with. I believe this is all too low.

Situated Context

The middle school I worked in at the time of this study had about 2,000 students. At my school site, CAST student performance exceeded the district and state of California but declined at the school itself. During the 2018-2019 school year, 46.08% of 638 8th grade students at the school met or exceeded the science standard, with that statistic falling to 39.59% of 634 8th grade students meeting or exceeding the same standard in the 2021-2022 school year (CAASPP, n.d.). Contrary to the trend seen at the state and district level, this number grew slightly to 41.92% of 582 8th grade students meeting or exceeding the standard during the 2022-2023 school year (CAASPP, n.d.), yet remains below pre-pandemic performance.

I had a unique role teaching 7th grade science and health within the Visual and Performing Arts (VAPA) magnet academy, at my school site. In addition to navigating the scope and content of the science curriculum as laid out by the NGSS, as a VAPA teacher I was responsible for integrating the arts into my content area teaching. The interdisciplinary expectation of the academy provided a clear opportunity for creativity in scientific problem-solving education.

In my personal experience over the years with my students, I noticed time and time again that they struggled to solve complex problems, and even more so when presented with problems they did not instantly recognize. The world my students have grown up in is one of instant gratification due to the wealth of information they can easily access through technological and societal advances. As a result, I witnessed students would give up easily when faced with a new challenge, particularly the academic ones. I noticed, even when they had previously encountered the subject matter knowledge required to engage with a problem, they tended to face a roadblock at one or all stages of the problem-solving process and were quick to dismiss problems as something they simply do not know how to solve. Most of my students had little difficulty memorizing and regurgitating information but struggled to use this information when it came to analysis, evaluation, and creation. Even a simple rephrasing of a question was sometimes enough to turn a simple problem into a daunting task.

Initially, being faced with a seemingly new and unforeseen challenge caused many students to quit before ever understanding the question. This is usually where they would skip the problem or throw out an arbitrary guess. If they found the determination to understand what was being asked, they may or may not attempt a solution. By accessing what they already know,

> humans naturally develop patterns of thinking modeled on repetitive activities and commonly accessed knowledge. These assist us in quickly applying the same actions and knowledge in similar or familiar situations, but they also have the potential to prevent us from quickly and easily accessing or developing new ways of seeing, understanding, and solving problems. (Dam & Siang, 2020, para. 8)

Students develop a relationship between what they have directly learned and what they consider is the extent of their knowledge or abilities in reference to a particular topic. When they are presented with an unfamiliar, or seemingly unfamiliar, situation in which they do not think their existing knowledge applies, they have difficulty in finding solutions to the problem.

To locally explore the opinions and experiences of other middle school science educators at my school site, I conducted interviews with 3 teachers. The interviews included ten open-ended questions regarding teaching and observing creativity and problem solving in the classroom. After analyzing my colleagues' responses, the following three themes emerged, which are discussed in further detail in Chapter 2:

- **Theme 1:** students need to be given opportunities through which they can employ their problem-solving skills.
- **Theme 2:** creativity and critical thinking must be taught and utilized together.
- **Theme 3:** students must understand that effective problem solving has purpose and value.

Students need to experience the impact of creativity and critical thinking on real-world problems to value this skill and attain the confidence and motivation to tackle problems when they see them. Creativity and critical thinking are not always paired concepts, so teachers must strive to present their students with opportunities to see how one enhances the other, encourage their creativity, motivate them to pursue critical thinking, and apply their efforts to purposeful challenges. Thus, future work should focus on implementing creative problem solving in the classrooms so students can acquire the understanding, the opportunity, and the practice that will enable them to combine their creativity and critical thinking skills and become effective real-world problem solvers.

Personal Context

My love for learning started at an early age. I enjoyed doing schoolwork, relished in solving puzzles, and had a voracious appetite for reading. School day instruction was supplemented at home with 1990's educational programming that made learning fun, by encouraging us to be creative, adventurous, and perpetually curious. Ms. Frizzle consistently urged me to "take chances, make mistakes, and get messy," something I remind myself of to this day. Annual trips to the research laboratory my father worked at on "Take your Daughter to Work Day" made science especially real for me and helped encourage my already growing interest in the discipline. Eventually, I went on to explore many scientific topics throughout my undergraduate education and earned my Bachelor of Science degree in biological sciences, with an emphasis in neurobiology, physiology, and behavior. During that time, I also worked within the Math and Sciences Teaching program at my university. I did not anticipate I would end up with a career as a middle school teacher back then, but life has a funny way of bringing things together for you if you let it.

My journey as an educator began eight years ago as a substitute teacher. I quickly found passion in using my time and presence to support students by distilling complex topics and providing support, strategies, and perspectives. Over the course of three years, I worked with thousands of students, and witnessed firsthand the barriers that often held students back from comprehension and critical thinking. However, one thing that was always apparent to me was that when given the opportunity, students could be creative in ways that would truly impress and inspire me. Encouraged to pursue my teaching credential by other teachers and school administrators, while subbing I began a dual program to earn my single subject science credential and Master of Education degree in secondary education and teaching.

When I began working as a credentialed teacher five years ago, I finally had the opportunity to design the experiences that my students would have in my own science class. I say experiences because for me, it goes beyond the act of designing a lesson, lab, or activity, creating a resource or assessment, or engaging in the routine of day-to-day curriculum and classroom management; it is instead about creating an environment in which students are engaged, given the space and time to explore ideas, and the resources and opportunities to form their own relationships with their thought processes.

As a lifelong puzzle enthusiast, I have always relished in the face of a challenge, and genuinely enjoy the process of figuring things out. When it became apparent to me that many students did not approach challenges in this same way, I felt very strongly that something must be done to better support them in the task of problem solving. In addition to differentiating my instructional practice and providing multiple means of engagement, representation, and expression for my students, I saw an opportunity to make problem solving more concretely accessible and relatable to them.

Years down the line, my students may not be able to recall the chemical equation for photosynthesis, or the transcription and translation process of DNA, and many may never even need to. However, I did not teach them science with the goal of instant recall due to rote memorization. Instead, I strived to create an environment where students were guided and encouraged to learn how to learn and think about their own thinking.

The hope is that by doing so, I gave my students the experience and confidence to engage in complexity of thought, ask important questions, explore their ideas, and express their creativity. Students who are accustomed to actively engaging with their own ideas and encounter complex problems or questions will not back away from them, believing that they have the tools to analyze and explore the problem, regardless of what it is. By practicing the critical and creative thinking necessary for problem solving, students will be more successful inside the classroom and beyond.

Problem of Practice and Intervention Overview

The problem I identified and engaged with in this study is that students struggle to demonstrate creative problem-solving abilities in the classroom. This problem is multifaceted, as it is guided by the expectations set forth by science curriculum and state testing, the ways in which teachers facilitate creative problem solving in their classrooms, and the attitudes and approaches with which students tackle creative problem-solving opportunities and learning at large.

To address this problem of practice, I designed an intervention to implement problem-solving strategies into content area instruction which I have called Creative Cognitive Process Instruction (CCPI). I designed this intervention to be used in a middle school science classroom to support students' creative problem-solving abilities, within the scope of the standard science curriculum. The CCPI intervention scaffolds the problem-solving process by integrating creative and metacognitive strategies into an instructional process that fosters mindful engagement, encourages creativity, and improves student metacognitive regulation. My research aimed to address the extent to which creative and cognitive instruction strategies may change students' metacognitive regulation and their attitudes and approaches toward creative problem solving. My study followed a teacher research/action research methodology, and utilized mixed methods, collecting both qualitative and quantitative data. My approach to this study incorporated the instructor-led modeling of metacognitive and creative strategies and student-led independent implementation of such strategies through problem-solving exercises within a curricular unit of study. The CCPI incorporated the Science and Engineering Practices (SEP) of the NGSS regarding problem solving and arts integration through creative and visual strategies.

Purpose and Study Design

This study examined the facilitation of a problem-solving process that fosters creativity and improves student metacognitive regulation in the classroom. Developing pedagogy to help students with the process of creative problem solving will not only help fulfill the interdisciplinary curriculum expectations in my classroom but will also be a useful skill for solving problems in their life, inside and outside of the classroom. This research may suggest how to enhance classroom practices to better emphasize the metacognitive and creative aspects students need to be successful problem solvers, foster the implementation of creative problem-solving strategies in other district classrooms, and support existing theories of the intersectionality of metacognition and creative problem solving.

Research Questions

Two research questions guided this study:

Research Question #1: How and to what extent does students' metacognitive regulation change after their experience with Creative Cognitive Process Instruction?

Research Question #2: How and to what extent do students' attitudes and approaches to creative problem solving change after their experience with Creative Cognitive Process Instruction?

CHAPTER 2

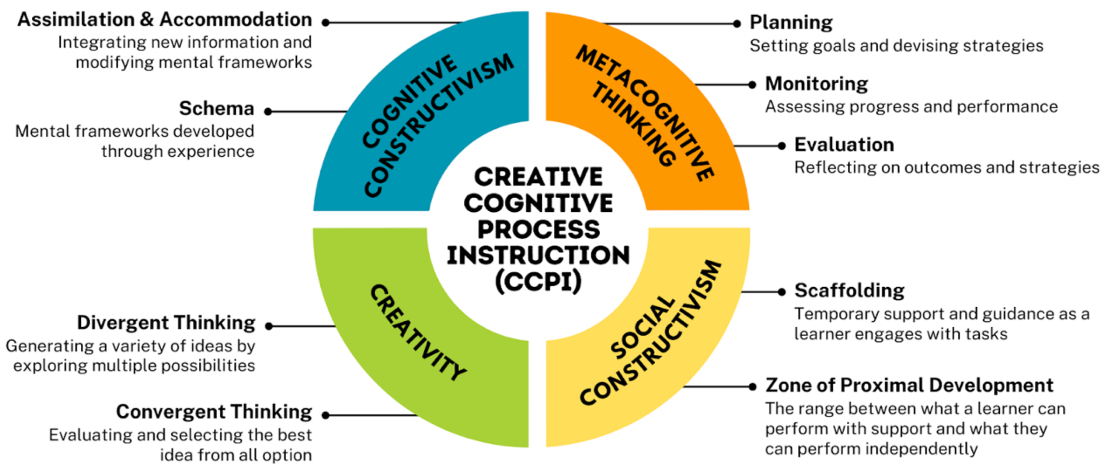
CONNECT: THEORETICAL PERSPECTIVES AND SUPPORTING SCHOLARSHIP

It “has often been claimed that traditional classrooms or teaching approaches do not focus on developing the creative faculty of students" (Carson, 2007, p. 9). One area where this creative faculty can be developed is in problem solving. Advocates of problem solving have asserted it develops students’ creative capacities (Frederiksen, 1984; Slavin, 1997 as cited in Carson, 2007, p. 9), and it promotes the development of effective thinking skills (Gallagher, Stepien, & Rosenthal, 1994; Hmelo & Ferrari, 1997 as cited in Carson, 2007, p. 10). These thinking skills fall within the self-regulation of thought, or metacognition. In 1985, Robert Sternberg argued that creative thinking involved self-monitoring through metacognition (Jia et al., 2019), and studies have found that metacognitive knowledge training promotes and significantly improves creative problem solving (Jia et al., 2019). In recognizing this consequential relationship between creative thinking and metacognition regarding problem solving, I have designed a creative problem-solving instructional sequence and process that incorporates metacognitive thinking strategies called Creative Cognitive Process Instruction (CCPI).

In this chapter, I explore the frameworks and perspectives informing my intervention and research design. I connect the ways in which I have brought together cognitive constructivist theories of knowledge construction, metacognitive thinking, creativity, and social constructivism to establish a creative problem-solving process. Founded on the complex interplay of constructive, metacognitive, creative, and environmental processes, the CCPI was intended to foster creative problem-solving skills among students. Figure 1 visually represents the organization of my theoretical framework and associated key concepts.

Figure 1

Theoretical Framework for CCPI and Associated Key Concepts



Cognitive Constructivist Theories of Knowledge Construction

Cognitive constructivism encompasses several epistemological and psychological theories "about the nature of knowledge and how it is formed through a knower's mental (hence cognitive) processes" (Hruby & Roegiers, 2012, p. 1). Cognitive constructivists believe that, in addition to the idea that knowledge or understanding is constructed, the structure of knowledge itself is crucial to its functionality (Hruby & Roegiers, 2012). Therefore, learning is relative to a student's stage of cognitive development, and "understanding the learner's existing intellectual framework is central to understanding the learning process" (Berkeley Graduate Division [BGD], n.d.).

As the name suggests, cognitive constructivism posits that knowledge is "actively constructed by learners based on their existing cognitive structures" (BGD, n.d.). While most “cognitive psychologists think of the mind as a reference tool to the real world” (Ertmer & Newby, 2013, p. 55) constructivists believe the mind filters input from the world to create a personal knowledge base built on interpretation and perspective (Jonassen, 1991).

Educational research in the 1950’s saw “learning theory [begin] to make a shift away from the use of behavioral models to an approach that relied on learning theories and models from the cognitive sciences” (Ertmer & Newby, 2013, p. 50). This shift saw the de-emphasis on observable behavior and stressed the conceptualization of complex internal cognitive processes like thinking, concept formation, and problem solving (Ertmer & Newby, 2013). With this emphasis on mental processing, learning became less about what learners do, and more about what learners know and how they acquire knowledge (Jonassen, 1991; Ertmer & Newby, 2013).

Cognitivism provides a foundation for understanding, as it focuses on a learner's mental activities leading up to a response, acknowledging their mental planning and strategies (Ertmer & Newby, 2013). To be effective, educators must structure instruction based on the student’s predisposition for learning and their existing mental structures, or schema (Ertmer & Newby, 2013). The following cognitivist principles outline how educators should design instruction:

1. Emphasis on the active involvement of the learner in the learning process (learner control, metacognitive training (e.g., self-planning, monitoring, and revising techniques))
2. Use of hierarchical analyses to identify and illustrate prerequisite relationships (cognitive task analysis procedures)

3. Emphasis on structuring, organizing, and sequencing information to facilitate optimal processing (use of cognitive strategies such as outlining, summaries, synthesizers, advance organizers, etc.)
4. Creation of learning environments that allow and encourage students to make connections with previously learned material (recall of prerequisite skills; use of relevant examples, analogies) (Ertmer & Newby, 2013, p. 53)

The origins of the constructivist theory of learning are often ascribed to Jean Piaget (1954) who believed the ability to conceptualize is not innate. Learners actively construct knowledge rather than passively absorb information. As they engage with the world and reflect on their experiences, they incorporate new information into their existing mental frameworks (schemas), and build new understandings (University at Buffalo, n.d.). Constructivist theory developed by establishing the need for learners to go beyond what they know and do something with that knowledge.

Author and researcher Richard F. Gunstone (1991) states the following assertions related to constructivist views of learning:

1. Each of us individually constructs our own meaning for experiences
2. Therefore understanding is individual, as individual constructions are different (although these individual constructions often have some commonality)
3. Much of the construction we undertake as we generate our own understanding involves linking new ideas and experiences with what we already know and believe (p. 129)

Together, these frameworks shift the focus of instruction from teaching to learning, from "passive transfer of facts and routines to the active application of ideas to problems" (Ertmer & Newby, 2013, p. 58).

In the classroom, I have seen students who are disconnected from the learning experience. On a day-to-day basis, this can be attributed to several human factors and vary from person to person. However, in a larger and underlying sense, the issue may be that students do not know the purpose(s) of what they are doing. This was observed in a study of New Zealand school science students and their perceptions of their science classes, where researcher Ross Tasker explored the students' sense of purpose regarding activities they had completed (Gunstone, 1991), and found this to be the problem. This study revealed "the most significant factor contributing to the problem is that students very often have extremely transmissive views of learning and teaching, and very passive views of the role they should play in these processes" (Gunstone, 1991, p. 132). Too often, students are focused on getting the right answer to a question, rather than engaging with "processes, supporting arguments, and alternate perspectives" (Gunstone, 1991, p. 132). I have regularly observed students who will put down almost any answer if they think there is a chance it could be correct and that they could then move on from the problem.

This problem of transmissive perceptions has two components. The first is the students' resulting conceptions and attitudes toward learning and solving problems. The second is the lack of regulation and control over their thought process or metacognition, the "amalgam of student knowledge, awareness and control relevant to their learning" (Gunstone, 1991, p. 135). My intervention has addressed these two components, as I designed my problem-solving survey to measure student attitudes and approaches to problem solving, and a creative problem-solving process to support their metacognitive regulation.

Piaget (1936) also theorized about cognitive development and suggested children move through four different stages of learning, believing their acquisition of schema and ability to assimilate and accommodate their schema grow through each phase. Specifically, the age range of middle school students falls within stage 4 of Piaget's 4 stages, known as The Formal Operational Stage. In this stage "adolescents can deal with hypothetical problems with many possible solutions" (McLeod, 2023a, para. 54), and should be able to follow a logical argument, think about abstract concepts, and logically test hypotheses (McLeod, 2023a). Piaget's identification of learners' abilities at this age indicates they should be capable of utilizing creative problem-solving skills.

Schema

A concept proposed by Jean Piaget, schemas (or schemata), are the building blocks that allow us to form a mental representation of something (McLeod, 2023a), or a problem solver's mental representation of a problem structure (Mayer, 1987). If I were to ask you to picture an island, the immediate mental image and understanding that you would get is your schema for what an island is. If I were to refine this to a tropical island, for example, your schema would then shift to accommodate your existing understanding and perception of this idea. As "knowledge comprises active systems of intentional mental representations derived from past learning experiences" (BGD, n.d.), studies have shown that children begin with basic schemata and, through experience, further differentiate them (Mayer, 1987). Therefore, the more they know about something, the more complex their schemas become, making it easier to "remember new information related to the schema - because there is more pre-existing information in our heads that [they] can relate - and thus attach - to it" (East Tennessee State University [ETSU], n.d.).

When it comes to students, schemas represent what they already know about a concept (ETSU, n.d.). They may have learned this information in different ways or places, have varying amounts of knowledge on the topic, and could even have stored incorrect information. Schema can also refer to processes or learning tools students have learned to identify and use. Therefore, as teachers, "our job is to either expand or correct their schemas about important concepts" (ETSU, n.d.). The key is that schema needs to come to mind when students are presented with information, meaning students need to be able to retrieve their schema before they can build on it. Thus, the first step is to "make sure students' existing schemas are up and running at a conscious level" (ETSU, n.d.). When it comes to science education specifically, it has been found that "training in schemata that are commonly found in the domain of science texts helped students learn how to organize meaningfully scientific information, and thus allowed them to more creatively use the information to solve problems" (Mayer, 1987, p. 339).

Assimilation and Accommodation

Piaget describes learning as the "interplay between two mental activities called "assimilation" and "accommodation" (Kalpana, 2014, p. 27). Simply put, assimilation is adding new information to existing knowledge, while accommodation is using new information to modify existing knowledge. Piaget did not believe that children learned passively, but instead through active sense making and adaptation. As children encounter new information, they can assimilate, by "attempting to interpret new information within the framework of [their] existing knowledge" (Cherry, 2022, para. 26), or accommodate, by "making small changes to that knowledge in order to cope with things that don't fit those existing frameworks" (Cherry, 2022, para. 27). Assimilation allows students to fit information into their existing schemas, while accommodation can lead to the development of new schemas. Once students adjust to their new understanding, they reach an equilibration, finding a balance between applying knowledge and adapting it (Cherry, 2022).

Application to CCPI Intervention

In the context of creative problem solving, learners draw upon their existing mental models (schemas) to comprehend and approach problems. These mental models influence how learners interpret problem statements, devise strategies, and navigate the problem-solving process. By assimilating and accommodating new problem-solving strategies into their mental frameworks, learners expand and refine their problem-solving skills.

I designed the CCPI to lead students through an approach for problem solving that integrates metacognitive and creative strategies into their existing schema for problem solving and aims to enhance the way they approach and work through problems and build new knowledge. One intended outcome was to help students slow down and think through the problem and what they know, guiding them away from tendencies to jump straight to a solution.

Metacognitive Thinking and Regulation

"Thoughts about thoughts, knowledge about knowledge, or reflections about actions" (Noushad, 2008, p. 6), metacognition, a term coined by researcher John Flavell in the 1970's, is the awareness one has about their own thought processes, or the way one thinks about their own thinking. Referring to "one's knowledge concerning one's own cognitive processes… metacognition refers, among other things, to the active monitoring and consequent regulation and orchestration of these processes…usually in the service of some concrete goal or objective" (Flavell, 1976, p. 232). Contrasted with cognition, which is purposeful thinking based on experiential knowledge, metacognition is purposeful thinking involved with problem solving that mediates between the learner and their cognition (Noushad, 2008).

While there have been many differing interpretations and analysis about the components of metacognition, Flavell (1979) classified it into "the three interconnected components of metacognitive knowledge, metacognitive experience, and metacognitive monitoring and control" (as cited in Jia et al., 2019, p. 2). When further considering the role that metacognition plays in active mental regulation and decision making within the problem-solving process, mental regulation can be simplified to indicate the cognitive processes of monitoring and control (Nelson & Narens, 1990).

Research shows that creative thinking may rely on metacognition in many ways. In 1985, Robert Sternberg argued that creative thinking involved self-monitoring through metacognition, and several studies have found that metacognitive knowledge training promotes and significantly improves creative problem solving (Jia et al., 2019). To further this assertion, on a biological level, "evidence from cognitive neuroscience studies reveals that the brain regions responsible for creative thinking overlap with the activated brain regions in metacognition monitoring and control" (Jia et al., p. 5). Due to this neurological overlap "creative thinking can be regarded as a metacognitive process in which the combination of individual's cognitive knowledge and action evaluation results in creation" (Jia et al., 2019, p. 3). This reinforces the claims that metacognition is "a logical conduit for developing creative problem-solving approaches in the classroom" (Hargrove & Nietfeld, 2015, p. 293), and that "explicit metacognitive instruction is necessary in educational settings to improve problem solving performance" (Hargrove & Nietfeld, 2015, p. 298).

To emphasize metacognitive instruction in the classroom, teachers must incorporate and model metacognitive strategies for their students. According to the Inclusive Schools Network (2014), "metacognitive strategies refers to methods used to help students understand the way they learn; in other words, it means processes designed for students to 'think' about their 'thinking'" (Perras, 2014, para. 10). When students become aware of and take ownership of their thought processes in this way, they are more easily able to determine what they know, and how to use it. It is easy to associate the role of a student with the act of learning simply for the fact that they attend school. However, learning itself is an action, and not an automatic consequence of being in an academic setting. While the expectation may be that learning happens naturally, in reality students must "learn how to learn" to gain control of their learning process and gradually develop the ability to master their mental processes more effectively (Perras, 2014). As students become aware of how they learn, they will use these processes to efficiently acquire new information, and consequently, become more independent thinkers (Perras, 2014).

There exists a complementarity between constructivism and metacognition where "an appropriately metacognitive learner is one who can effectively undertake the constructivist process of recognition, evaluation and, where needed, reconstruction of existing ideas" (Gunstone, 1991, p. 136). Therefore, the following constructivist principles align with the instructional design of metacognitive experiences:

1. An emphasis on the identification of the context in which the skills will be learned and subsequently applied (anchoring learning in meaningful contexts).
2. An emphasis on learner control and the capability of the learner to manipulate information (actively using what is learned).
3. The need for information to be presented in a variety of different ways (revisiting content at different times, in rearranged contexts, for different purposes, and from different conceptual perspectives).
4. Supporting the use of problem-solving skills that allow learners to go "beyond the information given" (developing pattern-recognition skills, presenting alternative ways of representing problems).
5. Assessment focused on transfer of knowledge and skills (presenting new problems and situations that differ from the conditions of the initial instruction). (Ertmer & Newby, 2013, p. 58)

In addition to developing metacognitive knowledge and skills, metacognitive strategies enable students to become increasingly autonomous in their learning, as they become aware of their strengths and weaknesses, and realize that success depends on their effort and strategies (Perras, 2014). Internalization of these strategies allows students to develop their own inner language, which enables them to develop the high-level cognitive skills associated with metacognition (Perras, 2014). These metacognitive skills allow students to manifest their own individual cognitive processing characteristics, which when combined with a creative mindset can help students regulate their ideas and engage in effective creative problem solving.

A study by Ryan Hargrove and John Nietfeld (2015) on the impact of metacognitive instruction on creative problem solving explored the facilitation of creative thinking and problem solving through a pedagogical approach that emphasized the development of metacognitive knowledge and skills. Their work utilized mental models to increase students' regulation of cognition, which they discussed as being necessary to monitor performance and develop self-regulatory skills (Hargrove & Nietfeld, 2015). Their findings indicated that teachers could promote their students' metacognitive awareness by engaging them in activities that require reflective thinking to "make the sometimes invisible work of thinking visible and explicit" (Hargrove & Nietfeld, 2015, p. 299).

When problem solving is broken down into its most fundamental analysis, it results in two phases (a) problem representation (the problem solver mentally represents the problem), and (b) problem solution (the problem solver performs mental operations on the representation to achieve a solution) (Mayer, 1987). These two phases directly correlate with the aspects of metacognition: metacognitive knowledge and metacognitive regulation.

Metacognitive Knowledge

Metacognitive knowledge is what one knows about their own cognitive processes (Stephanou & Mpiontini, 2017). When students possess a high level of metacognitive knowledge, they can adjust their thinking to be more adaptable problem solvers, transfer knowledge of strategies more efficiently to new learning situations, and perform better in the classroom than those with little or no metacognitive knowledge (Stephanou & Mpiontini, 2017).

I designed my intervention to establish procedural metacognitive knowledge by guiding students through the acquisition of metacognitive and creative thinking strategies, and a step-by-step problem-solving process. My hope was that by teaching metacognitive skills to students, they would enhance their metacognitive regulation abilities while engaging in the creative problem-solving process.

Metacognitive Regulation

Building on Flavell's original work, Brown (1978) emphasized the self-appraisal and self-monitoring aspects of metacognition (Paris & Winograd, 1990) that have come to be associated with metacognitive regulation. As the active component of metacognition, metacognitive regulation refers to the planning, monitoring, and evaluating activities learners engage in to facilitate learning and memory (Stephanou & Mpiontini, 2017).

Planning

The planning stage "involves the selection of appropriate strategies and the allocation of resources that affect performance" (Schraw, 1995, p. 354). This is an essential first step in the metacognitive regulation process, as it allows learners to determine how they will approach a task. Within the intervention, students are given opportunities to demonstrate their metacognitive planning by dissecting given information from the problem statement, examining their current understanding of the problem and their own knowledge on the subject matter, identifying information that they do not know and/or may need to find out, and brainstorming and organizing their ideas.

Monitoring

Metacognitive monitoring refers to one's own "awareness of comprehension and task performance" (Schraw, 1995, p. 355). For students to successfully engage in metacognitive monitoring processes, they must develop a sense of judgment or self-appraisal "that is essential in comparing, assessing, and evaluating the content or the process of one's learning" (Noushad, 2008, p. 7). The intervention provides students with opportunities to demonstrate their metacognitive monitoring skills by exploring and assessing their own understanding of the problem and the subject matter to determine if they have enough information to proceed. It also provides opportunities for students to analyze and assess their own critical reasoning to determine if their ideas and/or solutions are reasonable within the context of the problem, and identify their possible shortcomings in determining or explaining their solutions.

Evaluation

Metacognitive evaluation refers to "appraising the products and regulatory processes of one's learning" (Shraw, 1995, p. 355). The intervention provides students with opportunities to demonstrate their metacognitive evaluation skills by reflecting on their challenges and explaining how they navigated them. It also provides opportunities for students to reflect on their ideation process and justify the reasoning for the solution they chose. The intervention also supports students thinking about and describing alternative approaches they could have taken to solve the problem differently or arrive at a different outcome.

Application to CCPI Intervention

Metacognition is a critical component in understanding how students engage with complex problem-solving tasks. Metacognitive regulation is vital in problem solving as it involves strategic planning, monitoring the effectiveness of problem-solving strategies, and reflecting on the problem-solving process. Students' metacognitive abilities significantly influence their problem-solving approaches, fostering creativity and innovation in their solutions.

The main idea about metacognition as it pertains to academic learning is learning can be enhanced when students become aware of their own thinking as they read, write, and solve problems, and teachers can promote this awareness by teaching problem-solving strategies, and cognitive and motivational characteristics of thinking (Paris & Winograd, 1990).

My goal for CCPI is to introduce students to new problem-solving strategies to develop and enhance their metacognitive regulation in the areas of planning, monitoring, and evaluation. The step-by-step problem-solving structure provides many areas where students have opportunities to explore these metacognitive domains and practice the introspective tasks of thinking about their own thought processes. The CCPI was designed to help students be more active in the problem-solving process and access their thinking in a more conscious way allowing learners to gain more awareness of their own mental processes.

Creativity as a Cognitive Process

What does it mean to be creative? Creativity is a term commonly used, yet indistinct in meaning. This term is often casually utilized as if it has an accepted universal meaning, however in reality, “a standard definition of creativity has lacked consensus, as the construct of creativity is complex and different disciplines have distinct focuses” (Jia et al., 2019, p. 2). While many may attribute creativity as being related to abilities within the arts, “most researchers have viewed creativity as a problem-solving ability, namely, the ability to imagine novel or useful ideas or products in a given context” (Sternberg & Lubart, 1999, Runco, 2010 as cited in Jai et. al, 2019, p. 2).

This perspective is important because it expands the range of contexts in which someone can demonstrate creativity, and certainly allows it to be applicable in any area in which problem solving is concerned. This is because “creative thinking involves a series of cognitive processes” (Jia et al., 2019, p. 3), such as acquisition of domain-relevant knowledge and skills, investigation and critical examination, analyzing complexities, diversifying response options, and intrinsic motivation (Amabile, 1983). Since cognition has been found to be involved in creative processes, there certainly exists potential to enhance and sustain creative thinking by improving metacognitive thinking (Hargrove & Nietfeld, 2015).

Creativity is sometimes seen as more of an innate talent than an acquired skill. While some people may have stronger tendencies to think or perform in ways most analogous with the common notions of creativity, it would be inaccurate and limiting to deny creative potential because creative thinking can be learned and practiced. As Vint (2005) wrote, it is “a myth that creativity is a gift that few select people are born with” and everyone has “the potential to be creative and innovative” (p. 20). In my research and in my CCPI intervention, diverse, original, novel, and non-standard approaches to ideas, in any context, constitute creativity.

Divergent Thinking

Divergent thinking is "cognition that leads in various directions. Some of these are conventional, and some original. Because some of the resulting ideas are original, divergent thinking represents the potential for creative thinking and problem solving." (Runco, 2014, p. 400). Since divergent thinking allows the learner to explore many possible solutions for the same problem, it requires open-ended questions for which there exist multiple possible solutions (Runco, 2014). As a result, learners are able to utilize thought processes that can lead to the generation of creative ideas. Divergent thinking allows the space for creativity to take place because it does not confine the learner to just one way of thought. In fact, in their review of research methods in creativity studies, Long (2014) expressed that "researchers relied heavily on divergent thinking tests and problem-solving tasks or products to measure creativity" (p. 431-32).

A 2015 study on divergent thinking in visual arts education validated prior findings on the efficacy of explicitly teaching metacognition for self-regulation. Furthermore, it emphasized the effectiveness of explicit metacognitive instruction for cultivating skills like fluency and flexibility in divergent thinking (Van de Camp, et al., 2015). When further considering the role of visual integration within science curriculum and problem-solving tasks, "the use of images instead of words in the divergent thinking exercises could be an important tool" (Van de Camp, et al., 2015, p. 56). This is important when assessing whether modes of visual communication within a problem-solving framework would be beneficial to students and their metacognitive regulation. Hence, the suggestion that providing "instructional support in building up metacognitive knowledge about divergent thinking may improve students' creative processes" (Van de

Camp, et al., 2015, p. 47) implies that integrating visual strategies into divergent thinking could benefit students in the realm of creative problem solving.

Convergent Thinking

On the other hand, convergent thinking is aimed at finding the best answer or solution to a given problem. Because it can be seen as manipulation of existing knowledge (Cropley, 2005), convergent thinking has often been seen as a less creative aspect of problem solving. However, it has also been argued that “divergent thinking without convergent thinking can cause a variety of problems including reckless change” (Cropley, 2005, p. 408). Ultimately, it seems these two processes work best when they work together. Eysenck (1993, as cited in Jai et al., 2019) “framed divergent-convergent interactions as important to conceptualizations of creativity” (p. 2), with problem solving relying on the use of both (Runco, 2014). In this way, “creative cognition is an approach that explains creativity as a cycle of convergent and divergent thought processes occurring within an individual” (Sauder & Jin, 2015 p.3), as creative thinking involves both the “generation of novelty via divergent thinking, and the evaluation of novelty via convergent thinking” (Cropley, 2005, p. 406-407).

Students will have opportunities to learn both divergent and convergent thinking strategies as part of the CCPI intervention process, and opportunities to utilize them when engaging with the problem-solving exercises.

Application to CCPI Intervention

Creativity involves generating novel and valuable ideas or solutions by combining existing concepts in unique and unexpected ways. Creative problem solving necessitates the application of creativity as a cognitive process. Learners engage in divergent thinking to generate a variety of potential solutions through innovative ideation and then apply convergent thinking to analyze and select the most effective and reasonable solution to address the problem.

Students are introduced to divergent thinking strategies through the CCPI intervention ahead of engaging with the problem-solving tasks. Divergent and convergent thinking practices are woven into the tasks, encouraging students to think of as many different and unique solutions as possible, and then determining which they feel is the most effective or reasonable solution to the given problem.

Social Constructivist Learning Theories

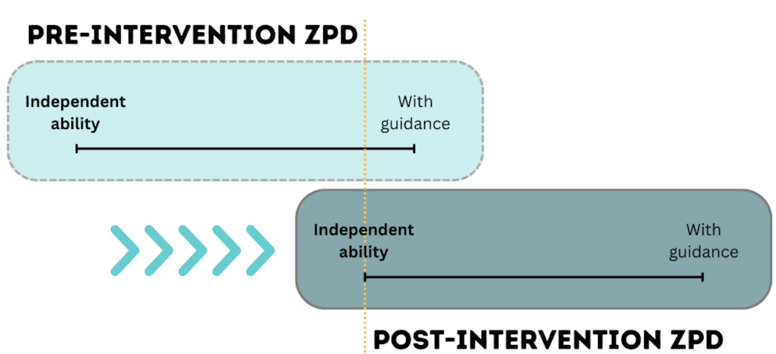
Developed in the 1930s by Lev Vygotsky, social constructivism argues that learning is a social and collaborative activity where meaning is created through interactions between people (Schreiber & Valle, 2013). Vygotsky advocated for learning as experiencing, emphasizing that a learning environment where students actively created their own knowledge was important (Schreiber & Valle, 2013). Central to social constructivism are pedagogical approaches that allow for peer collaboration and forming connections between students' prior knowledge and new knowledge (Azzarito & Ennis, 2003). One such approach is that of the authentic task. An authentic task is anything that a student is expected to do beyond receiving input of some kind, meaning that learners must take responsibility for their own learning from that point on (Bay et al., 2012). It is therefore significant for teachers to help learners acquire problem-solving skills like critical thinking, analysis, and synthesis, and for learners to possess and utilize these skills (Bay et al., 2012). Metacognition plays an intermediate and significant role in producing critical thinkers (Bay et al., 2012). Like Piaget’s cognitive constructivist theory, Vygotsky's social constructivist theory emphasizes an active approach to learning by the learner and meaningful experiences in which to do that learning. Where they differ is that the constructivist approach assumes students need guidance for knowledge production (Schreiber & Valle, 2013). In my study, I take the approach of starting with heavy guidance and support, then slowly weaning students off the support toward developing and demonstrating their problem-solving skills individually.

Zone of Proximal Development (ZPD)

The zone of proximal development "refers to the difference between what a learner can do without help and what he or she can achieve with guidance" (McLeod, 2023b). This is the space where learners are developing their capabilities between what they can accomplish with support and what they can do without support. One of the goals of my intervention in this study is to observe whether metacognitive strategies can help students utilize guided support to shift their personal ZPD and enhance what they are able to do independently. Figure 2 provides a visual model of how a student's independent abilities may develop within their ZPD.

Figure 2

Development of Independent Abilities in Student's ZPD



Scaffolding

The idea of helping students evolve their independent abilities by first providing them with support was built into Vygotsky's (1978) ideas, as he stated:

> Any higher mental function which has emerged in the process of human historical development appears on the scene twice. It first appears as a form of interaction and co-operation among people, as an interpsychological category. Then it appears as a form of individual adaptation, as a part of an individual's psychology, as an intrapsychological category. (p. 128)

Building on Vygotsky's work and other studies in early learning, psychologist Jerome Bruner determined that a framework, which he called scaffolding, must be provided using familiar and routine contexts to aid children in learning (Foley, 1993). Like the meaning of scaffolding in construction terms, which refers to a temporary structure used to stand on while building, in education it is a teaching strategy for providing assistance while students practice mastering new skills and concepts (Structural Learning, 2021). According to Bruner's scaffolding theory, "when students are provided with the support while learning a new concept or skill, they are better able to use that knowledge independently" (Structural Learning, 2021, para. 17).

Application to CCPI Intervention

Social constructivist theories emphasize the social and collaborative nature of learning, with peer interactions, teacher guidance, and scaffolding influencing students' problem-solving approaches. Using social constructivist ideas, creativity can be fostered through learning experiences that integrate various viewpoints and strategies, and scaffold learners towards independent practice over time.

Through CCPI, students begin with learning metacognitive and creative strategies and work on scaffolded problem-solving tasks collaboratively to gain confidence and develop their skills. Over time, the level of support is reduced as they work through problem-solving tasks, to facilitate a gradual shift through their ZPD, ideally improving their independent problem-solving skills.

Creative Cognitive Process Protocol

As cognitive constructivism urges that knowledge is actively constructed, learning can be presented as a process of active discovery (BGD, n.d.). A teacher's role is therefore to facilitate that discovery by "providing the necessary resources and by guiding learners as they attempt to assimilate new knowledge to old and to modify the old to accommodate the new" (BGD, n.d., para. 3). Bloom and Broder's (1950) research on question-answering skills concludes that an instructional process must distinguish between the products of problem solving and the process of problem solving. Instruction should focus on the "teaching of useful problem-solving strategies and processes, rather than on reinforcing students for emitting correct responses" (Mayer, 1987, p. 340).

Several approaches to problem solving already exist. While many of them utilize different approaches and terminologies, they are similar in that they all begin with a point of entry to a problem and end with an element of evaluation or reflection. When considering which problem-solving methodologies I could use for a creative process in my classroom, I struggled to find one that was a just right fit for my students, my context, and my content. I found it imperative to use a protocol that was process-focused and helped students break down the barrier of entry to the problem, form connections between their knowledge, utilize creative approaches, and think about their own thinking.

Ultimately, utilizing my own experience as a classroom teacher, I decided to piece together steps I believed would make the most sense for the grade level, subject matter, and students that I teach. With that in mind, I created the Creative Cognitive Process Protocol (CCPP) (see Figure 3).

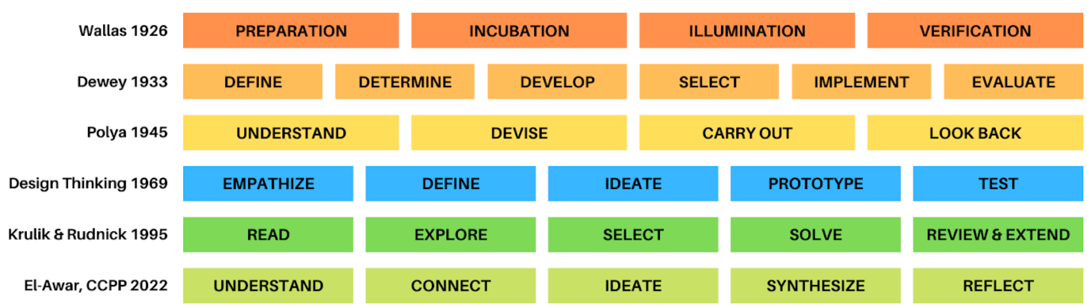
Figure 3

Creative Cognitive Process Protocol (CCPP)

Figure 4 illustrates a chronological comparison of some problem-solving sequences that have emerged over the years, along with my CCPP.

Figure 4

Chronological Comparison of Problem-Solving Sequences



The CCPP is the step-by-step process that students use when completing Problem-Solving Tasks (PSTs) during the CCPI intervention. It is designed to be used with problems that have a variety of possible solutions and connect to some amount of existing knowledge, allowing students to build and ideate. The structured approach is meant to help students focus on one aspect of problem solving at a time to allow for a better analysis and understanding of student performance within each aspect.

Prior Cycles of Research

Action research is a recursive process consisting of cycles of research which affect previous and subsequent cycles (Pine, 2009). To validate my problem of practice, align my research purpose to the needs of my situated context, and develop tools for use in my study, I conducted two preliminary cycles of research.

Cycle 0

As previously mentioned in Chapter 1, to locally explore the opinions and experiences of other middle school science educators at my school site, I conducted a cycle of interviews in the spring of 2021 which included ten open-ended questions regarding teaching and observing creativity and problem solving in the classroom. I coded the data from these interviews in accordance with Strauss and Corbin's (1998) constant comparative method from grounded theory by grouping together relevant words spoken by the participants, which I then categorized as properties and finally coded as responses to my research questions.

After analyzing my colleagues' responses, I identified three themes. The first theme is that students need to be given opportunities through which they can employ their problem-solving skills. It was often mentioned that problem-solving opportunities have been taken away from middle school students, whether by parents, teachers, curriculum, or technology, resulting in a lack of familiarity and patience when presented with a problem that does not have an instant or clear solution. Students need to feel confident in their abilities to problem solve, and often, they really do not know where to begin. The next theme that I identified was that creativity and critical thinking must be taught and utilized together. A common belief is that being creative and being analytical are opposite and independent of one another. This was frequently stated by my colleagues as being far from the truth. When these two ideas are separated, the strength found at their intersection is lost. There are many students who excel at critical thinking but lack creativity, just as there are many students who are exceptionally creative but cannot think critically. My colleagues strongly advocate for the idea that outside-of-the-box thinking, through the synergy of creativity and problem solving, yields novel perspectives and alternative ideas. They firmly assert that problem solving is a tactical, cross-curricular skill that is enhanced through the infusion of creativity. The final theme I identified was that students must understand that effective problem solving has purpose and value. Teachers reported that often, students see certain topics or problems as abstract concepts that have little to no relation to them and what they experience in the world. When this happens, students disengage in the learning. The data I gathered shows that teachers believe students need to see things contextually to invest in them.

Cycle 1

In anticipation of designing a problem-solving protocol which would take students through a critical and creative thought process, I created a rubric to assess problem-solving exercises. In creating my rubric, I utilized my experience as a classroom teacher to lay out the components that I believe are necessary for problem solving, while infusing the criteria within each component with opportunities for the visual communication of information and thought processes as evidence of achievement.

My cycle 1 research, conducted in fall of 2021, was to validate the rubric and discuss with my peers the reliability of realistically using it to assess problem-solving tasks given to students. By starting with the rubric, validating it, and subsequently allowing myself to refine it during this cycle and beyond, I believed I would be better equipped to create an effective problem-solving protocol.

To collect quantitative data, I created a survey instrument that asked participants to rate the construction and functionality of the rubric on a four-point Likert scale ranging from strongly disagree to strongly agree for each question asked. The survey also collected relevant demographic data about each participant including current occupation, subjects taught (currently or previously), years of experience in education, whether they had experience in design thinking, and how strongly they believe that effective problem solving is essential. Respondents were also asked to rate the flexibility, inclusiveness, and creativity of the rubric, the adaptability to different subjects and learning types, as well as the likeliness that they would utilize it in their own curriculum on a four-point Likert scale. Finally, participants were given the option of providing additional open response feedback at the end of the survey and volunteering for an additional interview regarding their opinions. Quantitative survey data was analyzed for response distribution and results were used to complement qualitative data in the development of themes.

I collected qualitative data by interviewing willing survey participants through both online video conference and in person, after they had reviewed the rubric and completed the survey. I asked interviewees a series of ten interview questions. These questions were designed to explore teachers' opinions on the challenges students face when it comes to problem solving, as well as what they perceive to be the most important parts of the problem-solving process. They were asked to share their thoughts on methods of visually communicating information, and how they personally perceive creativity when assessing their students' work. Participants were also asked to indicate problem-solving techniques they utilize, as well as the likelihood that they would utilize a problem-solving process, and this rubric (as is or adapted) in their own practice. Overall, the interview process was meant to gain further information on the potential utilization of the rubric instrument, as well as their sense of creativity and problem solving in general and in the classroom. I transcribed and coded the interviews line-by-line, grouped initial codes accordingly and determined categories from each grouping of codes. Finally, I summarized these categories into several themes. Six themes emerged from this data:

Theme 1: Comprehension is an essential first step of the problem-solving process. This theme was supported by interview responses which indicated students struggle at the point of entry to a problem, they lack understanding when presented with a problem, and they need a clear understanding and goal before they can begin.

Theme 2: Exposure to higher level thinking skills leads to more effective problem solving. This theme was supported by the interview responses which indicated students do not have enough exposure to higher level thinking tasks, direct instruction creates an inauthentic approach to problem solving, and higher-level thinking is required on a larger scale.

Theme 3: Problem solving must be taught as an iterative process. This theme was supported by the interview responses which indicated students need an opportunity to reflect, there is a circular aspect to problem solving, it may take multiple tries to arrive at a solution, and students should have chances to attempt multiple iterations.

Theme 4: Creativity lies in non-standard approaches. This theme was supported by the interview responses which indicated creativity is outside-of-the-box thinking, there is no standard approach to creativity, creativity falls within a broad range of solutions, and creativity extends past the parameters of a problem.

Theme 5: There are many ways to solve a problem. This theme was supported by the interview responses which indicated there is often not only one correct solution to a problem, students should utilize trial and error, and they should not be afraid to try new things.

Theme 6: Standard problem-solving procedures can be adapted across disciplines. This theme was supported by the interview responses which indicated the rubric can be applied across content areas, it can be useful as a teaching tool, it should be tested in different classrooms, and it could be made simpler and/or more generic.

Application to CCPI Intervention

These early cycles of research informed my dissertation study when it came to understanding the needs of my situated context in relation to my problem of practice and designing my rubric and the problem-solving tasks that I would assess with it. The CCPI and CCPP provided students with opportunities to develop and employ problem-solving skills, which my early research determined was lacking in the classroom setting. The intervention focused on teaching high-level thinking skills, combining creativity and critical thinking together. There was also an emphasis on the importance of comprehension and establishing clear goals to help students break through the point of entry. Across the intervention, I would encourage students to think of many ways to solve a problem, produce a broad range of solutions, and utilize their creativity in non-standard ways that extend beyond the given parameters. The goal was, with enough exposure to exercises like these, students would find meaning and value in engaging with their own understanding and imagination to solve problems.

CHAPTER 3

IDEATE: METHODS

Action research is a cyclical and reflective process which allows practitioners to use their professional experience to identify a problem in their context, and work toward finding an actionable solution (Pine, 2009). Informed by theory, research techniques are used by practitioners to systematically examine their own practices, ask testable questions, and design interventions with the intention of working towards positive outcomes, improving conditions, and informing change in future practices and future cycles of research.

For teachers to have a hand in school improvement, they must be willing and able to critically examine their own practice as well as how students learn best (Mertler, 2020). While school improvement leaders may often look to educational research literature as the basis for guiding improvement efforts, the imposition of abstract research findings which generalize across populations does not tend to be very helpful (Mertler, 2020). To counter this continued imposition, “there is a real need for the increased practice of teacher-initiated, classroom-based action research” (Mertler, 2020, p.14).

Kurt Lewin, who coined the action research term, strongly believed the key to arriving at a solution to a problem or instituting change was to conduct research specifically within the context in which the problem exists (Mertler, 2020). Therefore, action research must focus on solving a specific school or classroom problem with the goal of improving practice or informing a decision at that site (Mertler, 2020). This requires the identification of a problem of practice that is situated within the professional educator's scope of work, and the educator becoming an active participant and active observer of the learning process (Mertler, 2020).

Teachers who are successful are those who systematically and consistently reflect on both their actions and the consequences of those actions to acquire new knowledge about the teaching and learning process (Mertler, 2020). This is only possible, however, when teachers are allowed, and encouraged, to take risks by making changes to their instructional practice (Mertler, 2020). Action research, therefore, gives teachers a real voice in their own professional development, increasing their confidence and professional self-esteem, and improving teachers' problem-solving skills (Mertler, 2020), giving them the opportunity to make actionable changes in the places where it matters the most.

This mixed methods action research study explored how and to what extent a scaffolded approach to problem solving incorporating creative, constructive, and metacognitive thinking strategies was valuable to 7th grade science students' metacognitive regulation and problem-solving attitudes and approaches. In doing so, my goal was to identify whether experience with the Creative Cognitive Process Instruction (CCPI) intervention could promote a transformative shift in student abilities, and which areas of instruction could facilitate a more creative and engaged problem-solving mindset.

The research questions explored in this study were:

Research Question #1: How and to what extent does students' metacognitive regulation change after their experience with Creative Cognitive Process Instruction?

Research Question #2: How and to what extent do students' attitudes and approaches to creative problem solving change after their experience with Creative Cognitive Process Instruction?

Setting and Participants

After receiving IRB approval from the university (see Appendix A) and my school district, I conducted this study in my own 7th grade science classroom within the Visual and Performing Arts (VAPA) Magnet academy at a public middle school in Southern California from March through June of 2023. I implemented the intervention specifically within the Ecology unit of study with associated instruction and problem-solving tasks completed during regular class time, and pre- and post-intervention surveys completed outside of instructional hours, as per district policy.

At the time of this study, I had 92 students enrolled in my class across three 7th grade science class periods. Students in all three class periods experienced the intervention in teaching (creative problem-solving instruction alongside science content standards), but only the work of those who received parental consent and provided their own assent was used in this research. Recruitment materials consisted of email correspondence and electronic consent/assent form. To recruit students to participate in the study, I provided parents/guardians with an overview of the study via email and students with an overview of the study in class. Parents/guardians were asked for consent via Google form, and students whose parents provided consent were then sent the student assent form with the pre-intervention survey. Overall, the consent forms were sent to the parents/guardians of 92 students, and I received responses providing consent for 52 students. Of the 52 students who then received parental consent, 33 responded providing their assent for the inclusion of their work in this study. The inclusion of data collected from student participation was voluntary, and all students received the same classroom instruction regardless of participation in the research. Confidentiality was maintained by not using any personally identifiable information regarding the students in the data analysis.

Role of the Researcher

Action researchers "play an active role in weaving together the different threads of influence with which [they are] presented over time, resulting in a well-grounded conviction" (Wicks et al., 2008, p. 19). As a classroom teacher who had served within this situated context for the last five years, I had seen my students engage with the 7th grade science curriculum and became convinced that students needed better support in the trials of problem solving that arise in the classroom. As I worked to navigate my students' problem-solving struggles through scaffolding and differentiation in the physical classroom, teachers and students were collectively thrust into the virtual classroom during the global COVID-19 pandemic. While technology had already become a common integration in the average classroom prior to distance learning, it became the exclusive option during, and maintained a prominent place in our everyday instruction once we returned to in person classes. The benefits and opportunities that technology provides to students and teachers in the classroom, and in education at large, are tremendous; however, it does not come without its negatives as well. Today, questions are immediately answerable via Google search, and it is easier to copy and paste an answer than understand it. Students who already struggled with problem solving beforehand no longer needed to think about their thinking to get by in school.

Problem solving is such an essential skill to learn and to practice. These students will undoubtedly go on to exist in a world with even more technology as the years go by. Just in the few short months between proposing my research and conducting it, access to artificial intelligence became universally available overnight, completely changing the landscape of how we access, create, and use information. However, it is my steadfast belief that the inability to regulate and create with our own thoughts and ideas will be a downfall to creative and critical thinking at large. As an action researcher, I am committed to "developing [my] own understanding and practice in ongoing ways" (Wicks et al., 2011, p. 19). Therefore, I have placed the utmost importance on my opportunity as an educator to provide students with the opportunities and resources to develop their own metacognitive processes, learn how to learn, think about their thinking, and creatively express their ideas.

Intervention Overview

I implemented the CCPI intervention over the course of approximately five weeks with time allowed before and after for consent, assent, and pre- and post-intervention surveys (see Appendix B for calendar of implementation). I chose to schedule this intervention during our Ecology unit of study, with CCPI instruction and Problem Solving Tasks (PSTs) interspersed between regular unit instruction and bookended by pre- and post-intervention surveys. I conducted lessons on metacognitive regulation, my Creative Cognitive Process Protocol (CCPP), and divergent thinking through whole class discussions and activities, before engaging with four PSTs. Table 1 outlines the intervention activities and research tasks of the study.

Table 1

Timeline of the Intervention and Research

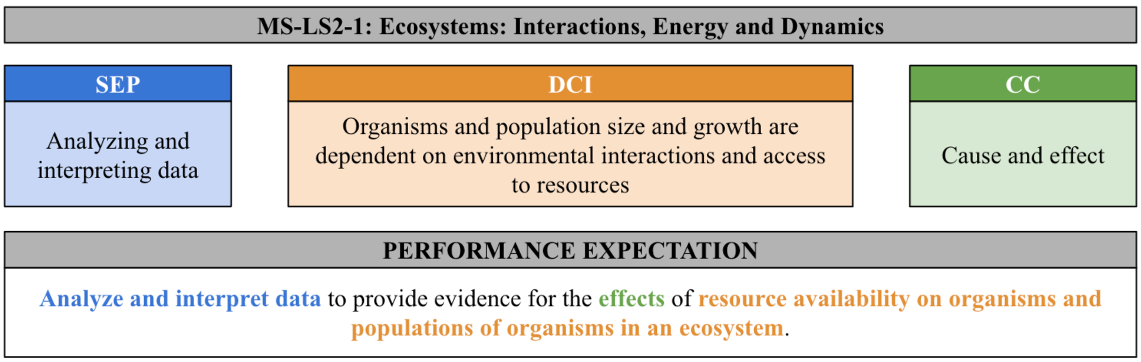
Sequence	Intervention Activities	Research Tasks
January 2023		• Create implementation schedule within Ecology unit • Select NGSS standards to use for PSTs
February 2023		• Design PST template • Create 4 PSTs through rounds of feedback and revisions
March 2023	• Content instruction • Introductory lesson	• Introduce the study • Recruitment of participants • Consent forms distributed via email to parents/guardians
April 2023	• Content instruction, activities, and assessments • Metacognitive strategy instruction • Introduction to CCPP • Divergent thinking instruction	• Assent forms and pre-intervention survey distributed via email to students • Administer pre-intervention survey • Maintain practitioner's journal • Collect teaching artifacts
May 2023	• Content instruction, activities, and assessments • Teacher guided problem-solving exercise (PST 1) • Collaborative problem-solving exercise (PST 2) • Independent problem-solving exercise (PST 3) • Independent problem-solving exercise (PST 4)	• Maintain practitioner's journal • Collect student work • Assess student work • Provide feedback to students (PST 2 and PST 3)
June 2023		• Provide feedback to students (PST 4) • Administer post-intervention survey

Prior to the intervention, I had to design the lessons and tasks the students would experience. The process of designing the PSTs was, in itself, an exercise in problem solving. I had to *understand* the purpose of my study and the needs of my students, *connect* the performance expectations of the science standards to each task through engaging science content, *ideate* and create many possible designs of the problem statements and task guides, *synthesize* an artifact that utilized the CCPP to facilitate metacognitive regulation and divergent thinking, and *reflect* through multiple rounds of feedback and discussion with my committee and colleagues. Through many iterations of this process, I created four PSTs.

In creating the PSTs, I specifically aligned the goals of each of the four tasks with the Science and Engineering Practices (SEPs) connected to the NGSS standards within the Ecology unit of instruction and created problem scenarios set in various ecosystem environments. I designed these problems to have multiple solutions, be well suited for multi-step problem solving, and provide opportunities for students to demonstrate their proficiency in meeting the associated NGSS performance expectations. Each SEP anchored the performance expectation for the task in an actionable problem-solving goal. Figure 5 is an example of how I identified the three dimensions of the Next Generation Science Standards (NGSS) within the performance expectations, which provided the problem-solving objectives for my PSTs.

Figure 5

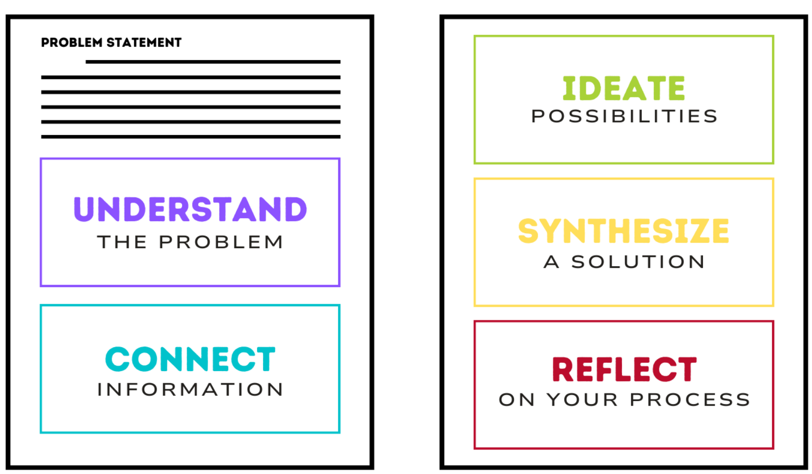
Components of the NGSS Performance Expectations



Students completed the PSTs on paper and the design of the PST served as a graphic organizer for the five steps of the CCPP. Each PST guided students through prompts and questions in each section to understand the problem, make connections between information, ideate possible solutions, synthesize a solution, and reflect on their process. Figure 6 illustrates the layout of the PST as a graphic organizer for the five-steps of the CCPP.

Figure 6

Problem Solving Task Sheet Layout



I had begun Ecology content instruction approximately four weeks before the start of the intervention. This instruction consisted of note taking, activities, assignments, and projects that introduced students to and allowed them to practice working with the topics in alignment with the NGSS standards for this unit of study. I continued with Ecology content instruction throughout the study.

I began the CCPI intervention with a lesson on the concept of metacognition. I facilitated a whole class discussion on the topic, where I introduced the idea of thinking about your own thinking, and broke metacognitive regulation down into planning, monitoring, and evaluating phases. Students participated interactively via Jamboard (a digital, collaborative whiteboard) to post their initial thoughts and mental associations for each phase. During this class period, I also introduced students to mind mapping as a way to organize ideas and form connections. Each class chose their own "real world" situation to create a mind map for, and students collaboratively identified ideas that branched through the planning, monitoring, and evaluation phases for the situation they chose.

On the next school day, I guided students through an open whole class discussion of the problem-solving steps within my CCPP. We again utilized Jamboard so students could provide their own thoughts and ideas about what came to mind when they thought about each of these steps, and what they thought each step might look like in practice, followed by class discussion.

The following day, I began the lesson by asking students to recall the five steps of the CCPP and then explained we would be focusing on the ideation step. I asked students what they thought divergent thinking might mean and they raised their hands and responded with what came to mind. After a brief discussion, I introduced them to the 30 circles challenge, where they were given a one-page template with 30 blank circles all the same size. Students were asked to draw as many different things as they could think of in 10 minutes that were either in the shape of a circle or used the circle in some way. After students had completed their challenge, I asked them to input short descriptions of each item they had drawn into an online word cloud generator. We generated one word cloud per period and analyzed the responses together as a class. After these three lessons, I continued Ecology content instruction for about one week before beginning the first PST, and in between each PST as well.

Students completed four PSTs over the next three and a half weeks. To engage students in the PSTs, I designed a scaffolded support sequence where I started by leading the class through the first problem task (PST 1), which was completed collaboratively as a whole class over the course of two days, incorporating student discussion and feedback throughout. Two days later, students worked on PST 2 over two days, with less support, unguided, working in pairs or groups of three. I took four school days to assess student performance against my PST rubric, during which I continued regular instruction, and returned the PSTs to students for teacher guided, whole class feedback. The next day, I gave students PST 3, removing instructor and peer support, asking them to complete the task independently over two class periods. I once again assessed student work against the problem-solving rubric and returned PSTs to students two days later for another teacher guided, whole class feedback session. The next day, students completed their final task (PST 4), which was also completed independently over two class periods. I assessed this work over a three-day holiday weekend and returned the graded PSTs to students upon returning for our final session of teacher guided, whole class feedback. Table 2 details the

NGSS standards, performance expectations, and problem scenarios for each of the four PSTs.

Table 2

Problem-Solving Tasks

PST	NGSS Standard	Performance Expectation	Problem Scenario
1	MS-LS2-1	Analyze and interpret data to provide evidence for the effects of resource availability on organisms and populations of organisms in an ecosystem.	Students were given a data set from a jungle ecosystem to analyze in order to interpret the cause and effect relationships between fluctuating populations of monkeys (prey), jaguars (predator), and fruit trees (monkey's food source) over time, and design a solution to restore balance to the ecosystem.
2	MS-LS2-2	Construct an explanation that predicts patterns of interactions among organisms across multiple ecosystems.	Students were given a description of organisms in a coral reef ecosystem and their interactions with each other. They were also told that coral growth in this area is being negatively impacted and were given a description of nearby human activities taking place. They were asked to describe the relationships between the coral reef organisms, predict how the problem with the coral growth may impact those relationships, and design a solution to the problem.
3	MS-LS2-3	Develop a model to describe cycling of matter and flow of energy among living and nonliving parts of an ecosystem.	Students were given an account of a species of salmon introduced to a lake in a developing town in the early 1900s, the other organisms in this lake environment, and the species of shrimp that was added as a food source in the years after, but instead became an invasive species. They were asked to develop a model to map out the flow of energy between organisms and determine the impact of the invasive species and design a solution to restore some balance to this ecosystem.
4	MS-LS2-4	Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations.	Students were given data about a forest ecosystem including the fluctuations in populations of warblers (prey), hawks (predators), caterpillars (warbler's food source), amount of rainfall, and introduction of parasitic fungus, and an invasive bird species over several years. They were asked to evaluate the relationships between all components of this ecosystem and construct a well-supported argument to explain how these changes have affected the population changes of warblers and hawks.

Data Collection and Analysis

A mixed methods research study is one which utilizes both qualitative and quantitative approaches to provide a better understanding of a research problem than either type could do on its own (Mertler, 2020). In this study, I used a mixed methods concurrent triangulation design to collect, analyze, and interpret my data. The qualitative and quantitative collection tools for this study are discussed in detail in the following sections and organized in Table 3 below.

Table 3

Data Collection Methods by Research Question

Research Question	Qualitative Source	Quantitative Source	Data Collection Tool
RQ 1: How and to what extent does students' metacognitive regulation change after their experience with CCPI?	Student work	Rubric scores	PST 3, PST 4[a]
RQ 2: How and to what extent do students' attitudes and approaches to creative problem solving change after their experience with CCPI?	Open-ended survey responses	Likert scale survey responses	Attitudes and Approaches Pre- and Post-Survey
		Rubric scores	PST rubrics (PST 2, PST 3, PST 4[b])

[a]Only independently completed PSTs were used for this RQ
[b]PST 1 was completed as a class with teacher guidance and student copies were not collected or analyzed

Data Collection Tools

I collected qualitative data from my teaching materials, student PST work samples, pre- and post-intervention surveys, and my practitioner journal. I formally analyzed PST work samples and survey results as part of my findings. While I did not formally analyze my teaching materials and practitioner journal, I revisited and reflected on each across my analysis processes. I collected quantitative data from the pre- and post-intervention surveys and PST rubric scores from my assessment of student work samples, formally analyzing both for inclusion in my findings.

Artifacts

The artifacts I collected across this study included teaching materials and student PST work samples. Teaching materials consisted of the CCPI resources I created, including lesson slides, and the resulting collaborative classwork. Student work consisted of work samples from the collaborative problem-solving exercise PST 2 (n = 31), and the two independent problem-solving exercises PST 3 (n = 29), and PST 4 (n = 31). Since we completed the first PST together as a class, I did not use it for data collection. Each time students finished PSTs 2, 3 and 4, their work samples were collected and given to a colleague who de-identified and returned them to me for grading. After grading the work samples, I digitally scanned and securely stored PST worksheets and marked rubrics from students who assented to the study for data analysis. I qualitatively analyzed PST samples for evidence of metacognitive regulation and quantitatively analyzed rubric scores across PSTs for evidence of student achievement over time on the PST as a whole, each CCPP subsection of the PST, and items pertaining to metacognitive regulation. CCPI teaching materials were used for personal reflection.

Survey

Prior to beginning the first CCPI lesson, I administered the pre-intervention survey (n = 33) to measure students' preliminary attitudes and approaches to problem solving. After the CCPI intervention was completed, I administered the post-survey (n = 28). I administered both surveys only to students who had assented and had parental consent to participate in the research. These students completed the surveys outside of class time, via Google forms. The pre- and post-intervention surveys (see Appendix C) I administered were adapted from a survey developed by Andrew Mason and Chandralekha Singh (2009) for college level physics students to measure the shifts in student attitudes and approaches to problem solving from the beginning to the end of their term. I selected 14 Likert scale response items applicable to problem solving at the middle school level and then removed the physics specific language. I organized the 14 questions into the following five constructs:

- Motivation/Determination: attitude toward beginning or continuing to solve a problem
- Divergent Thinking: exploring many possible solutions or ways of thinking
- Connection to Existing Knowledge: how well can you use what you have already learned?
- Visual Communication: Representing thoughts and ideas through images
- Reflection: Thinking back on the steps that have been taken

The original survey items had five-point Likert scale responses ranging from *strongly disagree* to *strongly agree* with a neutral option in the middle, however I decided to remove the neutral option and used a four-point Likert response scale instead: *strongly disagree, disagree, agree,* and *strongly agree*. These survey responses were quantitatively analyzed. For the purposes for this study, I also added free response questions to the survey about student approaches to problem solving (one that was on both pre- and post-surveys, and one additional that was just on the post-survey) and two demographic questions to collect qualitative data.

Practitioner Journal

I maintained a practitioner journal over the course of the intervention as an instrument for examining my own teaching (Mertler, 2020). In my journal, I maintained a detailed account of what took place in each CCPI lesson to note insights and interesting observations. As a researcher, this journal aided my recollection. As a practitioner, it allowed me to adjust the intervention as needed based on my ongoing observations. I did not formally analyze or code the journal, but the anecdotal notes allowed me to reflect on the intervention's events and my own perceptions at the time of the study, and to incorporate those ideas into my final analysis.

PST Rubric

I modified the rubric I created during my Cycle 1 research to better fit the PST content and structure and used it to assess student work on PST 2, PST 3, and PST 4 (See appendix D). The rubric consisted of a four-level proficiency scale, and quantitative data was collected from students' average scores on each PST, average scores by CCPP section on each PST, and average scores by metacognitive regulation domain on each PST.

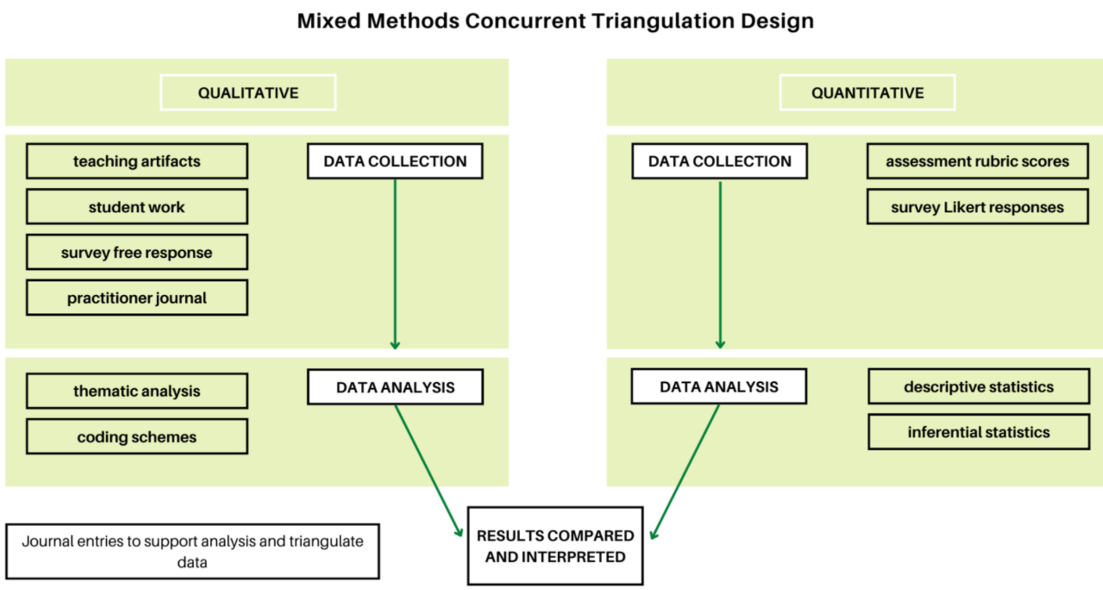
Data Analysis

I utilized a mixed methods concurrent triangulation design to collect, analyze, and interpret my data. I first began with quantitative analysis of the pre- and post-intervention surveys and PST rubrics before moving on to qualitative analysis of pre- and post-intervention surveys and PST work samples. After establishing my quantitative and qualitative findings, I triangulated them to identify where they had convergence and divergence, and integrated that analysis into the answers to my two research questions.

The qualitative and quantitative data analysis methods I used for this study are discussed in detail in the following sections. Figure 7 shows an overview of the triangulation process.

Figure 7

Mixed Methods Concurrent Triangulation Design Map



Quantitative Analysis Methods

I analyzed the quantitative data by comparing pre- and post-intervention survey results and PST scores over time using SPSS software. When assessing the reliability of each survey construct using Cronbach's coefficient of reliability, I determined that these constructs were not reliable as grouped ($\alpha < 0.7$), indicating that student responses were not consistent within each of these categories. This could have been attributed to either a poor interrelatedness of the questions within each construct, or the small number of questions (3-5) within each construct. To improve the reliability of my analysis, I decided to instead evaluate all 14 questions as one construct called *attitudes and approaches*, and determined that the post-intervention survey was sufficiently reliable after removing one survey item (question #5) for a total of 13 questions, and a reliability of $\alpha = 0.71$. I used these 13 questions for the rest of my analysis regarding the pre- and post-intervention surveys.

I scored survey responses in two different ways. First according to the four-point Likert scale responses which, for computational purposes, I reassigned with values of 1 through 4 accordingly before quantitative analysis. Pre- and post-surveys were also scored against the "expert-like" responses indicated on the answer key of the original survey that the questions were derived from. The "expert-like" responses were meant to indicate more favorable attitudes and approaches to problem solving, while non- "expert-like" responses were meant to indicate less favorable attitudes and approaches. Students received a score of 1 for each question that matched the expert response, and -1 for each question that did not. Survey scores were averaged for each student to give them their "expert-like" score. From this data I created three student groups which I used in analyses: *more expert* (for students whose scores became more "expert-like" after the intervention), *less expert* (for students whose scores became less "expert-like" after the intervention), and *no change*.

In addition to analyzing student performance for all participants as one group and by "expert-like" scores, I wanted to see if there were differences in attitudes and approaches based on student PST performance. I chose to split student data by percentiles into thirds based on their average scores on their final task (PST 4). I ranked students' average PST 4 scores from highest to lowest and divided them into thirds to create three groups: top scoring, middle scoring, and low scoring.

I conducted paired samples t-tests of the pre- and post-intervention survey data to determine whether there was a shift in student attitudes and approaches after the intervention. These tests were conducted on the survey as one construct for both scoring methods on the following participant groupings:

- Difference between pre- and post-survey responses
    - All students
    - Top, middle, and low scoring groups by final task (PST 4) scores
- Difference between pre- and post-survey responses scored by "expert" responses
    - All students
    - More expert, less expert, and no change groups

and I used descriptive statistics to look at individual survey items more closely for groups split by expert-like survey responses. Additionally, I conducted a one-way analysis of variance (ANOVA) to compare pre- and post-survey responses between groups split by PST 4 score, and a Chi-square test was used to compare students' enjoyment and self-perceived proficiency with science pre- and post-intervention.

Again, as a reliability measure, I calculated Cronbach's alpha for the five CCPP sections of the rubric. I determined that all five sections: understand (α = 0.75), connect (α = 0.60), ideate (α = 0.85), synthesize (α = 0.73), and reflect (α = 0.62), could be considered reliable as constructs (Hair, et al., 2010). While two of these constructs were below the ideal threshold ($\alpha > 0.70$), this can be considered reliable given the action research study and smaller sample size. Repeated measures ANOVA were conducted to compare PST rubric scores between PST 2, PST 3, and PST 4, and means and standard deviations were presented to examine and describe the changes in student performance between tasks. I conducted these tests using average scores from the PST rubrics as a whole and average scores on each CCPP section of the rubric, for a range of participant groupings:

- Difference in average scores between PST 2, PST 3, and PST 4
    - All students
    - More expert like, less expert like, no change groups
    - By response: enjoy/don't enjoy science, do well/struggle in science
- Difference in average scores by CCPP section between PST 2, PST 3, and PST 4
    - All students
    - More expert like, less expert like, no change groups

Finally, I used descriptive statistics to look at individual rubric items pertaining to the three domains of metacognitive regulation: planning, monitoring, and evaluating for comparison in scores across PST 3 and PST 4.

Qualitative Analysis Methods

I analyzed the qualitative data by coding pre- and post-survey free response questions to understand changes in students' attitudes and approaches toward problem solving after the intervention, and coding student PST work samples to analyze how students engaged within the areas of the CCPP related to the domains of metacognitive regulation. I started with inductive analysis of the shared free response question on the pre- and post-surveys, using in-vivo coding as an initial coding method on student responses. I combined in-vivo codes into conceptual categories, and further grouped into axial codes as a secondary coding method. Finally, I grouped together axial codes to form the four theoretical codes or themes that emerged from this analysis. I then started coding responses from the second question on the post-survey, first through in-vivo coding and then deductively using the conceptual categories I created from the analysis of the first question and creating new categories with whatever did not fit. The results from the first and second survey questions were compared and discussed in my findings. I then moved on to analysis of student PST work samples to analyze changes in the domains of students' metacognitive regulation after CCPI. I narrowed down the large number of artifacts by randomly selecting nine students work samples and analyzing only the independently completed tasks PST 3 and PST 4 for each ($n = 18$). I started with deductive analysis by process coding the PST template to identify the areas I attributed to planning, monitoring, and evaluation. From those groupings, I then inductively coded each item to create process subcodes. When analyzing student work for each subcoded item, I used magnitude coding to identify whether the student engaged with their thought processes in a thorough or limited manner. Finally, I compared my findings between PST 3 and PST 4 to analyze for change. Qualitative data was analyzed with quantitative data to answer my research questions, along with personal reflection on my lesson plans and practitioner journal.

Reliability and Validity

Action research requires practitioners to systematically examine their own practices. As a teacher researcher conducting a study in my own classroom and with my own students, it was important to be aware of the factors that may have influenced my research due to my deep connection to my context. Factors that I considered with regard to validity in my study were (a) experimenter effect, (b) sample attrition, and (c) construct validity.

Experimenter effects are "errors introduced during the collection or analysis of experimental data due to the behavior of the experimenter" (Kuipers & Hysom, 2014). Experimenter effects can occur without notice, and without ill intent, but still have widespread impact, from choosing a research topic, to interacting with research participants, to biases in data interpretation (Nichols & Edlund, 2023). In my study, I had to consider the experimenter effect because my students understood that I, as their teacher, was conducting a study for my doctoral dissertation, and that the instruction sequence to follow was a part of this study. All students participated in the intervention, however, only student work from those who assented to data collection contributed to my analysis. I cannot know for sure the extent to which knowing their work would be analyzed as part of my study might have impacted who ultimately assented to data collection. However, it is possible that students' perceptions of the study's content, the idea of participating in it, or even me as their teacher could have played some role (positive or negative) in their choices or behavior.

I did many things to try and mitigate my personal influence during this study. Regarding recruitment, I maintained neutrality, reiterating to students that their participation in data collection was completely voluntary and neither choice would affect their grade or class experience. I provided reminders when consent/assent forms and survey responses were due, as children need reminders, particularly since they could not complete surveys during instructional time per district policy but did not encourage nor discourage recruitment or completion of surveys. Regarding support during PSTs, I provided no answers or ideas, but did answer clarifying questions when they were asked during collaborative work. Further, I also refrained from answering questions related to the PSTs during independent work. Finally, grading can be quite subjective. Even with a structured rubric, a grader can have tremendous personal influence over the outcome. Since asking someone else to grade this massive amount of work was not feasible, I made sure that work samples were de-identified by a colleague prior to me grading them and avoided looking at work samples while supporting students in class so I would not associate any samples to specific students when I later assessed them.

Because I designed the lessons, the problem tasks, and did the grading, I did play a significant role in this study - however, this is also what teachers do in regular practice, so in that regard, it is reflective of an authentic teacher experience.

My study may have also been affected, to some degree, by sample attrition. Sample attrition is the "result of subjects being omitted from analyses because of data deficiency reasons (e.g., incomplete posttest, missing data on critical variable)" (Rivers, p. 3, 1985). As I was not allowed to administer surveys during instructional time, I had to rely on students to remember to do something optional in their free time. This can sometimes be a large ask for middle schoolers. I again maintained neutrality and tried to mitigate this with several reminders. Reminders help children significantly, however in the end I still ended up with five fewer post-surveys completed than pre-surveys and so could not use the data from those students when trying to compare pre- and post-survey results. Additionally, there were students who were absent on PST days, needed more time to finish, or simply chose not to finish. For those who were absent or needed more time, I provided them with opportunities to complete their tasks within a reasonable time frame, so as not to disrupt or overlap the timeline of other tasks in the study. As their teacher, I encouraged all students to try their best, but for those students who chose not to complete their tasks, I was ultimately left with a smaller set of data to analyze.

Finally, as discussed earlier, the constructs in my survey did not prove to be statistically reliable and so I had to utilize my survey as one whole construct. I believe that I could have mitigated this by validating the survey constructs ahead of the intervention, perhaps in a previous research cycle.

CHAPTER 4

SYNTHESIZE: DATA ANALYSIS AND FINDINGS

This mixed methods action research study examined the effects of Creative Cognitive Process Instruction (CCPI) on students' metacognitive regulation and attitudes and approaches to creative problem solving.

Results from this study are presented in two sections. The first section consists of the analysis procedures, and results from my quantitative data analysis of the pre- and post-intervention surveys and Problem Solving Tasks (PSTs). The second section consists of the analysis procedures and findings from my qualitative data analysis of the pre- and post-intervention survey, PSTs, and practitioner journal. In the following chapter, I triangulate my data for this mixed methods study to "generate stronger and more credible inferences or study conclusions by using integrated quantitative and qualitative study results" (Ivankova, 2015, p. 10), and discuss data complementarity to answer my research questions.

Quantitative Analysis

I collected quantitative data from Likert scale response questions on the pre- and post-intervention surveys, and the rubric scores from the PSTs that students completed during the intervention. I used SPSS to calculate Cronbach's alpha coefficient of reliability, paired samples t-tests, one-way analysis of variance (ANOVA), and Chi-square test of independence for the survey data, and Cronbach's coefficient of reliability, descriptive statistics, repeated measures analyses of variance (ANOVA), and paired samples t-tests for the PST rubric data.

Pre- and Post-Intervention Survey

I designed the pre- and post-survey to measure students' attitudes and approaches to problem solving before and after engaging with the intervention. On the same survey pre- and post-, students were also asked to indicate how they feel about science, whether they *enjoy* it and *do well* with it, *enjoy* it but *struggle* with it, *don't enjoy* it but *do well* with it, or *don't enjoy* it and *struggle* with it. I conducted inferential statistics on the survey as one reliable construct, $\alpha = 0.71$, called *attitudes and approaches* which consisted of 13 of the original 14 survey items. Additionally, I used descriptive statistics to discuss individual survey items where interesting. I analyzed the results from student responses to the Likert scale survey questions in the following ways:

1. Comparing responses between pre- and post- surveys (as one construct) for all participants together
2. Comparing responses between pre- and post- surveys (as one construct) for participants split in thirds by average score on PST 4 (high, medium, and low scoring students)
3. Comparing pre- and post- survey responses (as one construct) between groups (high, medium, and low scoring students)
4. Comparing pre-and post- survey responses to "expert-like" survey responses (as one construct)
5. Comparing the relationship between students' enjoyment and performance in science

Attitudes and Approaches Toward Problem Solving

I performed a paired samples t-test to evaluate whether there was a difference between the attitudes and approaches of students toward problem solving before and after they participated in the CCPI intervention. I ran the test on the survey as one construct (*n* = 13) for the group of 31 students who completed both pre- and post-intervention surveys. Results indicated that there was not a statistically significant difference in student attitudes and approaches before (*M* = 2.97, *SD* = 0.34) and after the intervention for the participant group (*M* = 2.97, *SD* = .029); (t_{27} = .000, $p > .05$, d = 0.00).

Attitudes and Approaches by PST performance. I then split the student data by percentiles into thirds by student's average scores on their final Problem Solving Task (PST 4). Students' average PST 4 scores were ranked from highest to lowest and then divided into thirds to create three groups: top scoring (*n* = 11), middle scoring (*n* = 10), and low scoring (*n* = 10). I again performed a paired samples t-test for each one of these groups. Middle scoring students had significantly lower attitudes and approaches toward problem solving after the CCPI Intervention (t_8 = -2.499, $p < .05$, d = -.83), and no statistically significant difference for the top scoring (t_{10} = 1.291, $p > .05$, d = .39), or low scoring (t_6 = .775, $p > .05$, d = .29), groups.

Attitudes and Approaches Between Groups. To compare the groups to one another, I performed a one-way ANOVA to evaluate the relationship between the highest, middle, and lowest scoring student groups on PST 4, and the changes in their attitudes and approaches to problem solving as measured by the pre- and post-intervention surveys. Descriptive statistics are presented in Table 4 below.

Table 4

Descriptive Statistics for Changes in Pre- and Post-Survey

	N	Mean Difference	St. Deviation
Group 1 (highest)	11	.08	.20
Group 2 (middle)	9	-.21	.25
Group 3 (lowest)	7	.08	.26

This analysis determined that there was a statistically significant difference between groups as determined by one way ANOVA, ($F(2, 24) = 4.44$, $p < .05$). A post hoc Bonferroni analysis indicated that the mean of group 1 was significantly higher than that of group 2 ($p < .05$). However, there were no statistically significant differences between the mean survey scores of group 2 and group 3 ($p > .05$) or between group 1 and group 3 ($p > .05$). This indicates that the students in the highest scoring group were more likely to agree that they employ the attitudes and approaches to problem-solving skills addressed in the survey than the middle scoring group.

Attitudes and Approaches compared to "expert-like" responses. I averaged survey responses scored against "expert-like" responses for each student and performed a paired samples t-test to evaluate the difference between pre- and post-survey scores for all students. Results indicated there was not a shift in pre-survey ($M = 0.51$, $SD = 0.22$) and post-survey scores after the CCPI ($M = 0.53$, $SD = 0.30$); ($t_{25} = .45$, $p = >.05$, $d = .09$).

I then split this student data, creating three groups: *more expert* (students who moved closer to the "expert-like" responses from pre to post survey), *less expert* (students who moved further from the "expert-like" responses), and *no change* (students who had no change in their responses). When I performed the paired samples t-test again on each of these groups, the results indicated that there was a statistically significant difference between pre- and post-survey scores for the students whose responses became more "expert-like," and a statistically significant difference between pre- and post-survey scores for the students whose responses became less "expert-like." Therefore, students whose responses became more "expert-like" did so significantly, and students whose responses became less "expert-like" did so significantly. Inferential statistics are given in Table 5.

Table 5

Inferential Statistics for Changes in "Expert-Like" Scored Pre- and Post-Surveys

Group	*M*		*SD*		t	*df*	*p*	Cohen's D
	pre-	post-	pre-	post-				
More expert	0.46	0.72	0.17	0.14	6.79	9	< .001	2.15
Less expert	0.56	0.34	0.27	0.36	-4.44	9	< .01	-1.41
No change	0.53	0.53	0.19	0.19	-	-	-	-

Although I treated the survey as one construct, I found it interesting that there was a marked difference in average student responses from the *more expert* group for question #12 which stated, "I usually draw pictures even if there is no credit for drawing them" between pre- (M = -.60, SD = .84) and post-survey scores (M = .60, SD = .84). From this, it appears that students whose overall attitudes and approaches became more favorable were more likely to indicate that they tended to draw pictures whether they would receive credit for doing so or not after the intervention.

There was also a notable difference between average responses from the *less expert* group for question #1 pre- (M = .00, SD = 1.054) and post-survey (M = -.80, SD = .632), which stated, "if I'm not sure about the right way to start a problem, I'm stuck unless I ask for help", and question #11 pre- (M = .40, SD = .966) and post-survey scores (M = -.40, SD = .966), which stated, "I am equally likely to draw pictures and/or diagrams when answering multiple-choice questions or a corresponding free-response question." From this, it appears that students whose overall attitudes and approaches became less favorable were more likely to indicate that they felt stuck unless they asked for help, and less likely to draw diagrams based on the type of question they were answering after the intervention.

Relationship Between Enjoyment and Performance in Science. I performed several chi-square tests of independence to evaluate the relationships between how students reported their enjoyment of science, and how they believed they perform in science before and after the intervention.

Students who indicated that they enjoyed science before the intervention were significantly more likely to believe that they do well in science before ($X^2(1, N=28) = 6.62, p < .01$), and after the intervention, ($X^2(1, N = 28) = 4.24, p < .05$), and also significantly more likely to indicate that they enjoy science after the intervention, ($X^2(1, N = 28) = 12.40, p < .001$), than were those who reported that they did not enjoy science before the intervention. However, those who indicated that they did not like science before the intervention were significantly less likely to believe that they struggled before and after the intervention, and significantly more likely to report disliking science after the intervention.

Students who indicated that they did well with science prior to the intervention were significantly more likely to report that they do well with science after the intervention, $X^2(1, N = 28) = 11.87, p < .001$, than those who indicated struggling prior to the intervention. Those who indicated struggling before the intervention were also significantly more likely to indicate that they struggle after the intervention than those who believed they did well before it.

There was no statistical significance between how students believed they performed in science before the intervention and their enjoyment of science after the intervention, ($X^2(1, N = 28) = 1.71, p > .05$), or between students' enjoyment of science after the intervention and how they believed they perform in science after the intervention, ($X^2(1, N = 28) = 0.66, p > .05$).

Problem Solving Task Rubric Scores

Students completed four PSTs during the intervention. PST 1 (see Appendix E) was instructor guided with whole class discussion, and therefore, was not assessed against a rubric. PST 2 (see Appendix F) was completed in pairs or small groups, and PST 3 (see Appendix G) and PST 4 (see Appendix H) were completed by students independently. PSTs 2, 3, and 4 were assessed against a rubric and scored. Each item on the PST corresponded with a criteria row on the rubric and was given a performance level rating from 1 (limited) to 4 (exemplary).

Analysis of Rubric Scores

By assessing each criterion on the rubric separately, I was able to analyze various aspects of student performance depending on which combination of criteria I chose to look at. I analyzed problem-solving task scores for each student in three ways:

1. Total average score (all criteria)
2. Average scores by section (criteria grouped by CCPP category: understand, connect, ideate, synthesize, reflect)
3. Scores of metacognitive regulation criteria
    1. Average scores for criteria grouped by metacognitive domain: planning, monitoring, evaluating

2. Scores for each criterion within these domains individually

Change in PST Scores Over Time. I performed a repeated-measures ANOVA to evaluate how average scores differed between PST 2, PST 3 and PST 4 for students who completed all three tasks. Descriptive statistics for these PST scores are presented in Table 6.

Table 6

Descriptive Statistics for PST Average Scores

PST[a]	*N*	Mean	St. Deviation
PST 2 average score	29	2.50	.24
PST 3 average score	29	2.49	.36
PST 4 average score	29	2.74	.45

[a]PST 1 was done as a teacher facilitated whole class activity, and therefore was not scored

The ANOVA model was significant [$F(2, 56) = 9.88$, $p < .001$], indicating that there was a statistically significant difference in average score across the three tasks. The change in average score decreased between PST 2 (completed in pairs) and PST 3 (first independent task), but this was not statistically significant ($p > .05$). However, an increased average score between PST 2 (completed in pairs) and PST 4 (second independent task), was statistically significant ($p < .05$), as was the increased average score between PST 3 (first independent task) and PST 4 (second independent task), ($p < .05$). Overall, student scores on their final PST showed a significant improvement over both previous scores.

Change in PST Scores Over Time by Section. I performed a repeated-measures ANOVA to evaluate how scores on each individual section of the CCPP differed between PST 2, PST 3 and PST 4 for students who completed all three tasks in each section. Descriptive statistics for the scores on each section are presented in Table 7. Sections that did not result in statistical significance for all participants as one group were further analyzed by PST 4 percentile groups (Group 1 - highest scoring on PST 4, Group 2 - middle scoring on PST 4, Group 3 - lowest scoring on PST 4).

Table 7

Descriptive Statistics for PST Average Scores by Section

	Understand *N* = 33[a]	Connect *N* = 29	Ideate *N* = 29	Synthesize *N* = 29	Reflect *N* = 29
PST 2	2.75	2.42	2.73	2.22	2.26
PST 3	2.51	2.41	2.72	2.41	2.29
PST 4	2.74	2.66	2.90	2.70	2.46

[a]*N* based on the number of students who completed each section on all three PSTs

Understand. Mauchley's test indicated that the assumption of sphericity had been met for student scores in the 'understand' section of the CCPP ($X^2(2) = 0.93$, $p > .05$) across the three PSTs. The difference between average scores in this section was significant at the 0.05 level [$F(2,64) = 5.53$, $p < .01$, partial $\eta^2 = .15$]. Post-hoc pairwise comparisons with a Bonferroni adjustment indicated that average scores on PST 4 were significantly higher than those on PST 3 ($p < .05$) and average scores on PST 3 were significantly lower than those on PST 2 ($p < .05$).

Connect. Mauchley's test indicated that the assumption of sphericity had been met for student scores in the 'connect' section of the CCPP ($X^2(2) = 2.08$, $p > .05$) across the three PSTs. The difference between average scores in this section was significant at the 0.05 level [$F(2,56) = 4.88$, $p < .05$, partial $\eta^2 = .15$]. Post-hoc pairwise comparisons with a Bonferroni adjustment indicated that average scores on PST 4 were significantly higher than those on PST 3 ($p < .05$) and PST 2 ($p < .05$).

Ideate. Mauchley's test indicated that the assumption of sphericity had been met for student scores in the 'ideate' section of the CCPP ($X^2(2) = 3.39$, $p > .05$) across the three PSTs. However, the difference between average scores in this section was not statistically significant at the 0.05 level. I ran the repeated measures ANOVA again on student data split by average PST 4 scores. The assumption of sphericity was met for the top scoring group ($X^2(2) = 4.59$, $p > .05$), and the difference between average scores in this section was significant at the 0.05 level [$F(2,20) = 8.37$, $p < .01$, partial $\eta^2 = .47$]. Post-hoc pairwise comparisons with a Bonferroni adjustment indicated that average scores on PST 4 were significantly higher than those on PST 2 ($p < .01$) for this group.

Synthesize. Mauchley's test indicated that the assumption of sphericity had been met for student scores in the 'synthesize' section of the CCPP ($X^2(2) = 0.71$, $p > .05$) across the three PSTs. The difference between average scores in this section was significant at the 0.05 level [$F(2,56) = 8.88$, $p < .001$, partial $\eta^2 = .241$]. Post-hoc pairwise comparisons with a Bonferroni adjustment indicated that average scores on PST 4 were significantly higher than those on PST 3 ($p < .05$) and PST 2 ($p < .01$).

Reflect. Mauchley's test indicated that the assumption of sphericity had been met for student scores in the 'reflect' section of the CCPP ($X^2(2) = 2.21$, $p > .05$) across the three PSTs. However, the difference between average scores in this section was not statistically significant at the 0.05 level. I ran the repeated measures ANOVA again on student data split by average PST scores. The assumption of sphericity was met for the middle scoring group ($X^2(2) = 2.75$, $p > .05$), and the difference between average scores in this section was significant at the 0.05 level [$F(2,20) = 5.38$, $p < .05$, partial $\eta^2 = .44$]. Post-hoc pairwise comparisons with a Bonferroni adjustment indicated that average scores on PST 4 were significantly higher than those on PST 3 ($p < .01$) for this group.

PST scores against "expert-like" responses. I performed a repeated-measures ANOVA to evaluate how average scores differed between PST 2, PST 3, and PST 4 for students split into groups based on which students moved closer to the "expert-like" responses from pre- to post-survey, which students moved further from the "expert-like" responses, and which students had no change in their responses. Descriptive statistics are presented in Table 8.

Table 8

Descriptive Statistics for Average PST Scores by "Expert-Like" Survey Scores

PST	*N*	Mean	St. Deviation
Group 1 (more expert-like)			
PST 2 average score	10	2.49	.24
PST 3 average score	10	2.64	.43
PST 4 average score	10	2.86	.60
Group 2 (less expert-like)			
PST 2 average score	10	2.51	.21
PST 3 average score	10	2.42	.33
PST 4 average score	10	2.77	.29
Group 3 (no change)			
PST 2 average score	6	2.54	.26
PST 3 average score	6	2.46	.36
PST 4 average score	6	2.66	.40

Mauchley's test indicated that the assumption of sphericity was not met for students whose survey responses become more "expert-like" between the pre- and post-surveys.

Mauchley's test indicated that the assumption of sphericity had been met for students whose survey responses became less "expert-like" ($X^2(2) = 1.50$, $p > .05$) between the pre-and post-surveys. The difference between average PST scores for students in this group was significant at the 0.05 level [$F(2,18) = 8.93$, $p < .01$, partial $\eta^2 = .50$]. Post-hoc pairwise comparisons with a Bonferroni adjustment indicated that average scores on PST 4 were significantly higher for this group of students than their average scores on PST 2 ($p < .05$) and PST 3 ($p < .05$). This indicates that although these students' attitudes and approaches to problem solving became significantly less favorable, their performance on PST 4 still improved significantly over the previous two PSTs.

Mauchley's test indicated that the assumption of sphericity had been met for students whose "expert-like" survey response score did not change ($X^2(2) = 3.33$, $p > .05$) between the pre- and post-surveys. However, the difference between average PST scores for students in this group was not statistically significant at the 0.05 level.

Changes in PST Scores by Enjoyment and Performance in Science. Repeated measures ANOVA were performed to evaluate how average scores differed between PST 2, PST 3, and PST 4 for students grouped by their pre- and post- intervention survey responses indicating whether they "do well" in science, "struggle" in science, "enjoy" science or "don't enjoy" science. This analysis was done for all students who completed both pre- and post-intervention surveys, as well as all three PSTs ($n = 26$). Descriptive statistics for the PST scores are presented in Table 9.

Table 9

Descriptive Statistics for Average PST Scores by Post-Survey Responses

	Do well		Struggle		Enjoy		Don't enjoy	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
					Pre-Survey			
PST 2	2.57	.18	2.43	.25	2.50	.22	2.53	.26
PST 3	2.62	.39	2.39	.34	2.52	.39	2.51	.36
PST 4	2.98	.40	2.55	.39	2.75	.45	2.88	.46
					Post-Survey			
PST 2	2.55	.20	2.41	.26	2.50	.23	2.56	.23
PST 3	2.63	.36	2.30	.32	2.53	.38	2.40	.38
PST 4	2.96	.37	2.44	.38	2.79	.45	2.73	.45

Mauchley's test indicated that the assumption of sphericity had been met for students who indicated that they "do well" in science ($X^2(2) = 1.05$, $p > .05$) on the pre-intervention survey. The difference between PST scores for students who indicated that they do well in science before the intervention was significant at the 0.05 level [$F(2,26) = 12.85$, $p < .001$, partial $\eta^2 = .50$]. Post-hoc pairwise comparisons with a Bonferroni adjustment indicated that average scores on PST 4 were significantly higher for this group of students than average scores on PST 2 ($p < .01$) and PST 3 ($p < .01$).

The assumption of sphericity was also met for students who indicated that they "struggle" in science ($X^2(2) = 4.88$, $p > .05$) on the pre-intervention survey, however the difference between PST scores for this group was not significant at the 0.05 level.

Mauchley's test indicated that the assumption of sphericity had been met for students who indicated that they "enjoy" science ($X^2(2) = 4.36$, $p > .05$) on the pre-intervention survey. The difference between PST scores for students who indicated that they enjoy science before the intervention was significant at the 0.05 level [$F(2,38) = 4.36$, $p < .01$, partial $\eta^2 = .27$]. Post-hoc pairwise comparisons with a Bonferroni adjustment indicated that average scores on PST 4 were significantly higher for this group of students than average scores on PST 2 ($p < .05$) and PST 3 ($p < .05$).

Mauchley's test indicated that the assumption of sphericity had been met for students who indicated that they "don't enjoy" science ($X^2(2) = 3.28$, $p > .05$) on the pre-intervention survey. The difference between PST scores for students who indicated that they don't enjoy science before the intervention was significant at the 0.05 level [$F(2,10) = 4.364$, $p < .05$, partial $\eta^2 = .47$]. Post-hoc pairwise comparisons with a Bonferroni adjustment indicated that average scores on PST 4 were significantly higher for this group of students than average scores on PST 3 ($p < .05$).

Mauchley's test indicated that the assumption of sphericity had been met for students who indicated that they "do well" in science ($X^2(2) = 1.39$, $p > .05$) on the post-intervention survey. The difference between PST scores for students who indicated that they do well in science after the intervention was significant at the 0.05 level [$F(2,32) = 16.43$, $p < .001$, partial $\eta^2 = .51$]. Post-hoc pairwise comparisons with a Bonferroni adjustment indicated that average scores on PST 4 were significantly higher for this group of students than average scores on PST 2 ($p < .001$) and PST 3 ($p < .001$).

Mauchley's test indicated that the assumption of sphericity had also been met for students who indicated that they "struggle" in science ($X^2(2) = 4.38$, $p > 0.05$) on the post-intervention survey. However, the difference between PST scores for this group was not statistically significant.

Mauchley's test indicated that the assumption of sphericity had been met for students who indicated that they "don't enjoy" science ($X^2(2) = 2.13$, $p > 0.05$) on the post-intervention survey. However, the difference between PST scores for this group was not statistically significant. The assumption of sphericity was not met for the group of students who indicated that they “enjoy” science ($X^2(2) = 6.25$, $p < .05$).

Students who went into the intervention believing that they do well in science scored significantly higher average scores on their final problem-solving task (PST 4) than the previous two tasks (PST 2 and PST 3). Alternatively, students who went into the intervention believing that they struggle in science did not have significantly different average scores on any of their PSTs.

Students who believed that they do well in science after the intervention also had significantly higher average scores on their final problem-solving task (PST 4) than on the previous two tasks (PST 2 and PST 3), and those who believed that they struggle in science after the intervention saw no significantly different average scores on any of their PSTs.

Students who indicated they enjoy science prior to the intervention scored significantly higher on their final problem-solving task (PST 4) than either of the previous two tasks (PST 2 and PST 3). Students who indicated that they don’t enjoy science prior to the intervention saw a statistically significant increase in their average scores between the two independently completed problem-solving tasks (PST 3 and PST 4), scoring significantly higher on PST 4, while there was no statistically significant difference between their scores on the partner assisted task (PST 2) and the final independent task (PST 4).

Neither group of students who indicated that they enjoy and don’t enjoy science after the intervention saw any statistically significant changes in their average PST scores.

Changes In PST Scores Related to Metacognitive Regulation. Although the PST rubric was not organized by metacognitive domain, I was curious to see how scores from rubric items that fell under planning, monitoring, and evaluating differed between the two independently completed PSTs (PST 3 and PST 4). The descriptive results indicated that the average scores for rubric items under planning, monitoring, and evaluating on PST 4 were all higher than the scores for planning, monitoring, and evaluating on PST 3.

I also looked at scores from each individual item within these metacognitive domains. For nine of the 10 questions evaluated, average scores increased between PST 3 and PST 4 (See Table 10). The areas where students seemed to make the most improvement were *dissecting given information, examining current understanding, identifying unknown information, analyzing own critical reasoning,* and *analyzing navigation through challenges.*

Three out of the four criteria assessed under planning showed a considerable improvement in student work between PST 3 and PST 4. One of three criteria analyzed this way under monitoring and one of three under evaluation also showed considerable improvement in student work between PST 3 and PST 4. Overall, students made their greatest improvements in planning. This is further discussed in the corresponding section under qualitative analysis.

Table 10

Descriptive Statistics for PST Subsections by Metacognitive Domain

Item	Process subcode	PST 3		PST 4	
		M	*SD*	*M*	*SD*
	Planning				
1p	Dissecting given information	2.52	.79	3.07	.88
2p	Examining current understanding	2.45	.69	2.76	.83
3p	Identifying unknown information	2.34	.55	2.76	.74
4p	Brainstorming and organization	2.79	.86	3.00	.89
	Monitoring				
1m	Exploring own understanding	2.45	.69	2.59	.68
2m*	Assessing own understanding	-	-	-	-
3m	Analyzing own critical reasoning	2.21	.62	2.76	.83
4m	Assessing own reasoning	2.55	.57	2.76	.87
5m*	Explaining possible shortcomings	-	-	-	-
	Evaluation				
1e	Analyzing navigation through challenges	2.30	.54	2.63	.57
2e	Justifying solution choice	2.30	.47	2.30	.73
3e	Reflecting on alternate approaches	2.31	.60	2.48	.63

*These items were analyzed differently, further explained in the qualitative findings

Qualitative Analysis

I collected qualitative data from open-ended response questions on the pre- and post-intervention surveys, student PST work samples, and my own practitioner journal. In the school setting, student progress is calculated with numbers and percentages which translate into a letter grade that serves as a representation of achievement. What numbers are not necessarily able to communicate, however, is understanding, perception, and creativity. The student voice is an essential element in establishing a deeper understanding of insight and abilities. Therefore, collecting and analyzing data that goes beyond numbers was important in this study, as "qualitative data contribute to teachers' nuanced understanding of students' individual growth, challenges, and experiential perceptions of classroom learning" (Ho, 2022, p. 4). I used the open-ended response survey questions to study students' attitudes and approaches towards creative problem solving, student PST work samples to explore their metacognitive regulation, and my practitioner notes to analyze my own understanding and inquiry throughout this study.

Pre and Post Open-Ended Survey Responses

I collected qualitative survey data from one open-ended response question (SQ1) on the pre-intervention survey, and two open-ended response questions (SQ1 and SQ2) on the post-intervention survey. The pre- and post- surveys had one question in common (SQ1) which asked students to describe their thought process when they encounter a problem that they do not immediately know how to solve. I analyzed student responses to this question on the pre- and post-surveys separately and then compared the ideas. In my qualitative analysis of the pre- and post-surveys, I used several coding methods associated with Grounded Theory but did not seek to move into theory construction. Charmaz (2014) discusses the immense effectiveness of Grounded Theory, noting that many researchers who aim for compelling synthesis of their data achieve their goals through Grounded Theory without diving into constructing theories. This is what I sought to do with my analysis.

I first analyzed student responses through in-vivo coding as an Initial Coding process to "prioritize and honor the participant's voice" (Saldaña, 2021, p. 138). I gathered 78 in-vivo codes from the student responses on the pre-intervention survey and 56 in-vivo codes from the same question on the post-intervention survey. I then grouped together codes referencing similar ideas into conceptual categories, such as grouping all mentions of sketching ideas and drawing diagrams as “visual aid for understanding.” Of the conceptual categories I created, 10 were shared between the pre- and post- surveys, 1 was predominantly found on the pre-survey, and 1 predominantly on the post-survey. As a Second Cycle coding process, I further grouped these conceptual categories by axial coding, which is the “transitional cycle between the First Cycle and Theoretical Coding processes of Grounded Theory” (Saldaña, 2021, p. 309). Through this method, I condensed the 12 conceptual categories into 7 axial codes. Finally, I grouped the axial codes into 4 theoretical codes, or themes, in the final analysis of students' attitudes and approaches toward problem solving from this open-ended survey question. Table 11 represents my organization of conceptual categories, axial, and theoretical codes derived from both pre- and post-survey qualitative analysis for the shared question (SQ1).

Table 11

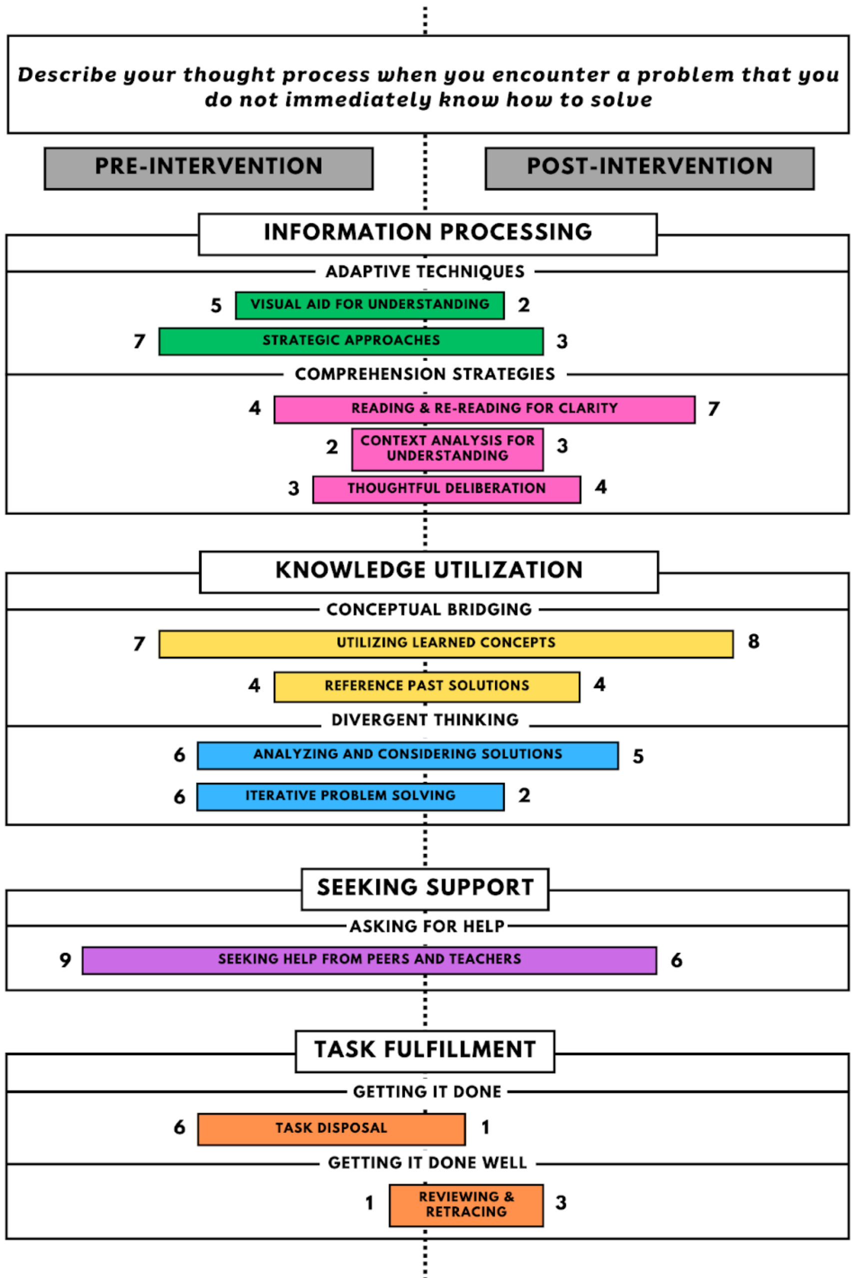
Analysis of Pre- and Post-Intervention Survey Responses for SQ1

Theoretical Codes	Axial Codes	Conceptual Categories
Information processing	Adaptive techniques	Visual aid for understanding
		Strategic approaches
	Comprehension strategies	Reading and re-reading for clarity
		Context analysis for understanding
		Thoughtful deliberation
Knowledge utilization	Conceptual bridging	Utilizing learned concepts
		Reference past solutions
	Divergent thinking	Analyzing and considering solutions
		Iterative problem solving
Seeking support	Asking for help	Seeking help from peers and teachers
Task fulfillment	Getting it done	Task disposal (pre- only)
	Getting it done well	Reviewing and retracing for accuracy (post-only)

Figure 8 visually represents SQ1 data as a side-by-side comparison between pre- and post-surveys and includes the response frequency for codes within each conceptual category.

Figure 8

Organization of Pre- and Post-Survey Responses for SQ1 with Response Frequency



The second open-ended response question (SQ2) on the post-intervention survey asked students to describe if and how their approaches to problem solving changed after practicing creative problem-solving strategies. While SQ1 was analyzed using inductive analysis methods, I targeted the analysis of SQ2 using deductive methods by fitting 41 in-vivo codes that I gathered from SQ2 into the existing conceptual categories that I created through my analysis of SQ1. I was able to assign 30 of these in-vivo codes to pre-existing categories and sorted the remaining 11 into three new categories that I created from coding this question, "persistence and effort", "proficiency", and "no change." Table 12 illustrates the addition of these categories from SQ2 along with the number of student responses for each category and theme across both questions.

Table 12

Quantity of Responses in Each Conceptual Category Across SQs

	When asked about what they do		When asked about what has changed
	Pre-intervention	Post-intervention	Post-intervention
Information processing	**21**	**19**	**22**
Adaptive techniques			
Visual Aid for understanding	5	2	3
Strategic approaches	7	3	9
Comprehension strategies			
Reading and re-reading for clarity	4	7	3
Context analysis for understanding	2	3	2
Thoughtful deliberation	3	4	5
Knowledge utilization	**23**	**19**	**5**
Conceptual bridging			
Utilizing learned concepts	7	8	0
Reference past solutions	4	4	0
Divergent thinking			
Analyzing and considering solutions	6	5	5
Iterative problem solving	6	2	0
Seeking support	**9**	**6**	**1**
Asking for help			
Seeking support from peers and teachers	9	6	1
Task fulfillment	**7**	**4**	**7**
Getting it done			
Task disposal	6	1	0
Getting it done well			
Reviewing and retracing for accuracy	1	3	2
Persistence and effort			3
Proficiency			2
No change reported			6

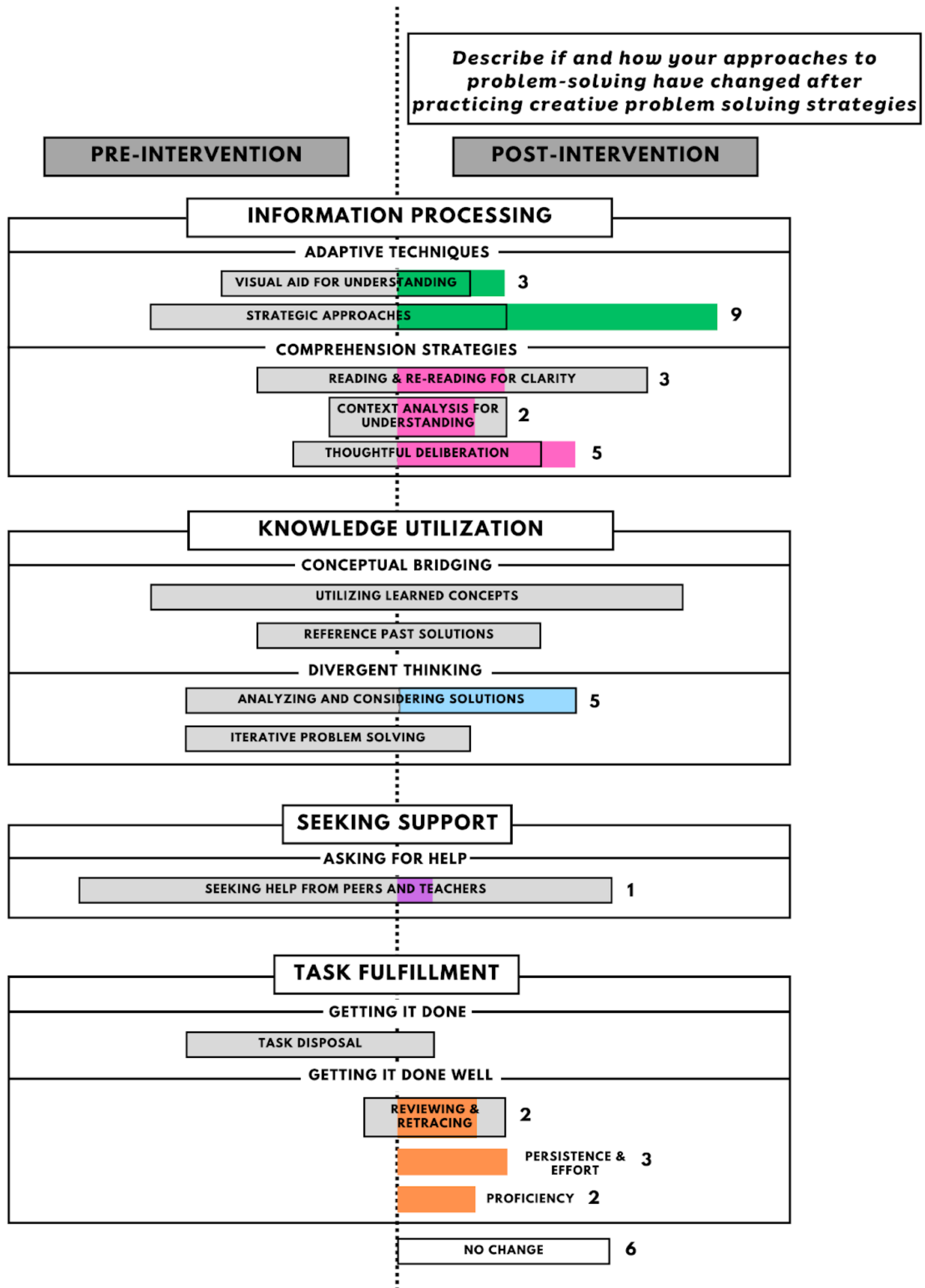
Findings: Pre- and Post- Open-Ended Survey Responses

All four themes I created incorporate student responses from both questions on the pre- and post-intervention surveys. In SQ1, I asked students to describe their approach to solving a problem they do not immediately know how to solve. Students answered this question once before participating in the CCPI intervention, and once after. In SQ2 I asked the students to describe directly if and how their approaches to problem solving have changed after practicing creative problem-solving strategies.

For each of the four themes, A, B, C, and D, I discuss my analysis of the SQ1 responses that I used for the construction, followed by my discussion of SQ2 responses and the attitudes and approaches that were present when students were asked to evaluate their own changes. When it came to self-assessing if and how their problem-solving approaches have changed after practicing creating problem-solving strategies, students' responses could largely be categorized within Theme A: Information Processing, and Theme D: Task Fulfillment. Figure 9 visually represents the organization and frequency of responses within categories that emerged from SQ2, mapped onto the results from SQ1 for comparison.

Figure 9

Pre- and Post-Survey Responses for SQ2, Mapped onto SQ1 Results with Response Frequency



Theme A: Information Processing

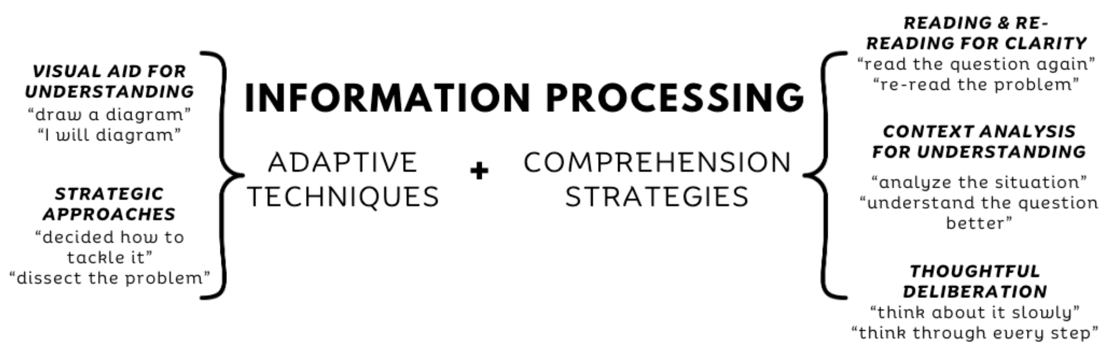
I created the first theme, Information Processing, by combining the axial codes of adaptive techniques and comprehension strategies. I created the axial code of adaptive techniques from student responses that referenced drawing diagrams as visual aids for understanding and methods of dissecting and deciding how to tackle the problem as strategic approaches. Student responses related to visual aid strategies included, “I usually draw a visual diagram so I can see what I am doing” and, “I sketch out and see possible solutions.” Student responses related to strategic approaches included, “I find context clues that could lead me to the answer” and, “I break it down into smaller parts that I do understand.” Through these adaptive techniques, students describe how they tailor their approaches, maintaining flexibility and adaptability appropriate for the problem's context and understanding of their own needs.

I derived the axial code of comprehension strategies from the instances where students emphasized their multiple passes at reading the problem to provide clarity, their analysis of the situations presented in the problem as a method for understanding, and a slow and deliberate approach to solving the problem. Student responses related to reading and re-reading for clarity explained, “I reread the text to gather more information” and, “I would take time carefully and thoroughly reading the problem until I understand it.” Student responses related to context analysis included statements like, “first I think about what the problem is asking me” and those related to thoughtful deliberation included, “I take a little while to think about how to solve the problem.” Through these mentions of comprehension strategies, students describe their efforts and commitment to understanding the underlying concepts and questions associated with the problem presented.

I brought together the adaptive techniques and comprehension strategies identified here under the theme of Information Processing (see Figure 10), pointing to the students' approaches to understanding the components of the problem and their commitment to developing solutions. These examples demonstrate students' willingness to invest time into understanding problems before moving on to finding solutions, and the growth in the number of comprehension strategies referenced post-intervention suggests that a focus on understanding the problem is what students found most useful when facing a new challenge.

Figure 10

Theme A: Codes and Categories with In-Vivo Examples



When analyzing responses to SQ2, students frequently referred to changes in their approaches that could be categorized as strategies for problem solving, for example, "reframe problems as questions," "try to look at the key concepts," and "take out… certain information that I need and remove the information that is not as important." The volume of this type of response was a bit surprising when solely compared to how many fewer students made references to strategic approaches in their SQ1 post response.

However, it seems like an ideal reference for students to make considering they were in fact exposed to many new strategies during the intervention. Another frequently noted change was in thoughtful deliberation, where students said, “now I take more time to think,” “I look more in depth into problems now,” and “I now think more about the problem.” By this analysis, I see a promising correlation between the breaking down and stretching out of problem-solving steps in the CCPP, and students whose problem-solving approach slowed down and became more thorough after engaging with it.

Reading and re-reading for clarity and context analysis for understanding were also mentioned as changes to student approaches. When asked about what changed, one student stated, “I used to not read through the questions thoroughly and I did not answer the whole question, or I missed some important information.” Being the first step of the CCPP, a focus on taking the time and making an effort to understand the problem before continuing was necessary, and the presence of these approaches as responses to SQ1 post- and SQ2 bodes well for the idea that students did actually learn how to employ comprehension skills when they encounter a problem. Finally, the students who indicated they now utilize visual aids for understanding stated, “drawing diagrams can be helpful” and they now have “new ways to sketch out possible solutions.” While analyzing student work samples, I saw examples of charts, tables, graphs, scientific diagrams, illustrations, mind maps, and other visual models. One of my goals with the CCPP was to encourage students to sketch out their ideas through any visual means, and while the number of students who indicated this as an approach for them on the survey was relatively small, every single student who completed their PSTs were able to utilize some form of visual representation in the areas of connecting information and ideating for solutions.

Overall, each of the five categories under Information Processing were referenced as a change in approach to problem solving, indicating that this was an area where students may have recognized new skills emerging and/or retained the most value from learning or utilizing these skills during the intervention. The emergence of responses within *all* categories in this theme, when students self-reported changes in their problem-solving approaches, bodes well for the idea that students acquired a range of strategies which help them process information before jumping into solving a problem.

Theme B: Knowledge Utilization

The theme of Knowledge Utilization emerged as I combined the axial codes: conceptual bridging and divergent thinking. Conceptual bridging was an axial code I derived from student responses related to linking the problem to information or ideas that they already know, and looking at, or thinking back to, previous work or similar problems they may have encountered or solved in the past. Student responses related to utilizing previously learned concepts included several methods such as "I think of all the methods I've been taught," "I try to retrace what we did during class," and "[I] look back on my notes." Student responses related to thinking back to past solutions included "I usually try to think about what I have solved that is similar to that problem" and "I think about how this problem might be similar in solution or understanding to ones I've solved in the past." These examples of the utilization of previously learned concepts and referencing past solutions showcase students' ability to integrate their knowledge and form connections between different domains of understanding. This type of integration highlights students' capacity to identify analogies, patterns, and solutions that may not be immediately evident by recognizing connections between existing information and their understanding of the current problem, and applying the appropriate elements from that information to their problem-solving approaches.

Divergent thinking is an axial code I derived from student responses related to thinking of many or different ways to solve a problem, and brainstorming multiple ideas and/or solutions, as well as making several and/or different attempts at solving a problem. Student responses related to analyzing and considering included “I think through the possible solutions and the different ways to solve it to get the answer” and “I will brainstorm ideas/solutions, to find the solutions.” Student responses related to multiple attempts at problem solving offered, “I will think of a way to do it first then if it does not work then I will try a different way” and that they “go through different attempts.” Responses in these categories demonstrated a willingness to explore multiple possibilities and generate a range of ideas. This may also indicate a creative approach that fosters an environment for unique and unconventional strategies, perspectives, and solutions, allowing students to diverge from linear thinking.

The Knowledge Utilization theme, comprised of conceptual bridging and divergent thinking (See Figure 11), therefore reflects students’ leveraging their existing knowledge while also exploring their own abilities for imaginative and innovative thinking. Additionally, this theme emphasizes curiosity and motivation can help students engage with problem solving in meaningful ways. The consistency in responses pre- and post-intervention referencing conceptual bridging, utilizing learned concepts, and referencing past solutions suggests that reflecting on prior work and existing resources is what students found most useful when facing a new challenge.

Figure 11

Theme B: Codes and Categories with In-Vivo Examples

Although I was able to gather many responses under the theme of Knowledge Utilization from SQ1 post-intervention, fewer students regarded these categories as something that had changed in their approach to problem solving. When analyzing responses to SQ2, I noticed this theme was relatively absent except for analyzing and considering solutions. Although this was the only category that emerged within this theme, the students' insights provide valuable information about processes that came directly from what they learned in the CCPP. For example, one student mentioned they now "balance divergent and convergent thinking" while another said, "I work better when I have multiple solutions to choose from." These examples of divergent thinking emerging as new approaches for students show promise for the usefulness of the divergent thinking strategies that students were taught through CCPI and illuminate an area of Knowledge Utilization that should be expanded on in both instructional efforts and student practice.

The students' penchant for conceptual bridging in the form of utilizing previously learned concepts and previous solutions for reference as indicated by their SQ1 pre- and post-intervention responses did not come through at all as a changed approach in their

SQ2. This could be due to students habitually engaging in this type of practice outside of the CCPP, or potentially that students do not necessarily see this as an "approach" to problem solving, and just something they do. Also missing in SQ2 was any mention regarding iterative problem solving. While several students did mention it as something they do when presented with a problem, it did not stand out as something that changed for them after the intervention. While the CCPP provided metacognitive checkpoints for students to re-evaluate their understandings and solutions, as well as an opportunity to reflect on alternate ways of solving the problem, it did not explicitly ask students to go through iterations of the process. This is also something to consider for future inclusion.

Theme C: Seeking Support

I created the theme of Seeking Support to illustrate student responses related to asking for help of some kind (see Figure 12). Students mentioned asking for help from various sources including asking the teacher, a classmate or peer, a friend, a sibling, or just "someone." While students indicated that they would ask for help when they encounter a problem they have not seen before on both the pre- and post-intervention surveys, the volume of these 'ask for help' responses decreased between the pre- and post-intervention surveys from 9 to 6.

Through my analysis of the student responses, I understand students may have diverse reasons for asking for help. When asked about their approach when they do not immediately know how to solve a problem, the majority of students indicated, to some degree, they would ask for help once they had already attempted the problem themselves, such as those who stated, "if I still can't solve it I ask my friends or teachers for help", "if it doesn't match up, I ask someone", and "if I still don't get it, I ask a fellow student next to me." While there were some students who indicated asking for help before attempting the problem, such as the student who stated, "first, when I encounter a problem, I will ask one of my good friends," it appears most students seek support after identifying their own limitations through trial and error. By engaging with the problem first, they have the opportunity to analyze its complexity and seek support to enhance their own understanding beyond their current knowledge.

Figure 12

Theme C: Codes and Categories with In-Vivo Examples

The number of students who reported they ask for help declined between SQ1 pre- and post-, and only 1 student noted this when asked about changed approaches in SQ2. While students will always seek support for topics that they are unfamiliar with, the scaffolded nature of the CCPP may have enabled students to guide themselves more effectively through the problem-solving process itself, particularly with the repeated practice of multiple PSTs. Overall, the decline in student responses stating they ask for help post-intervention suggests some students may feel more independent when facing a new challenge after experiencing the intervention.

Theme D: Task Fulfillment

While the themes of (a) Information Processing, (b) Knowledge Utilization, and (c) Seeking Support included similar responses to SQ1 on pre- and post-surveys, responses to SQ1 under the theme of (d) Task Fulfillment were quite different on the pre- and post-surveys. Additionally, this was the only theme to which I added categories after analyzing student responses from SQ2 on the post-survey. On the pre-survey, students indicated a sense of task disposal, or simply getting the problem done, with responses like "I just take my best guess," "I give up," or "I skip." Meanwhile, the responses on the post-intervention survey went beyond finding a solution to reviewing and retracing for accuracy, as indicated by students who responded, "after I'm done, I like to think about other possible outcomes," "retrace my steps if the problem doesn't come out the way I wanted it to," and "retrace my steps back to the problem to catch any mistakes." When I first identified these two ideas, I initially had them separated into two distinct themes. Upon further reflection, I decided they both belonged under the same umbrella, as they both encompass the students' presence or absence of motivation toward completing the problem and the presence or absence of their dedication to ensuring that they have done the best job possible.

This distinction between getting it done and getting it done well on the pre- and post-intervention surveys demonstrates a shift in student attitude toward task fulfillment after engaging with the CCPI intervention. Student responses that fell under task disposal resemble an outcome-driven mentality, hinging largely on how fast they could get past a problem they had not previously seen. These responses may demonstrate a surface-level engagement with the content and concepts presented, and therefore, potentially less comprehension and value derived from the problem-solving process. Conversely, student responses that demonstrated their willingness to review their solutions and retrace their problem-solving process for accuracy may be indicative of a deeper level of engagement with the context and concepts presented in the problem. Responses in this category indicated a focus on both accuracy and understanding, prioritizing their comprehension of the problem, and building on their foundation of knowledge and commitment to success.

After reviewing responses from SQ2, I saw no mentions that pertained to task disposal, and instead saw responses which strengthened the idea of students "getting it done well." I therefore attributed them accordingly under the theme of Task Fulfillment. In addition to responses about reviewing and retracing, students provided previously unseen insights regarding persistence and effort, as well as proficiency. Student persistence and effort were evident in responses like, "I now am not just giving up" and I "put more effort into finding a reasonable solution," while proficiency came through in responses like, "I feel more efficient while solving problems" and I "could be more fluent in doing a certain problem." Overall, the expansion of this idea of "getting it done well" illustrates a favorable shift in students' attitudes and approaches to problem solving after the intervention and indicates students may recognize the value derived from engaging with the CCPP with regard to how they feel about their own inclinations and abilities. Figure 13 illustrates the organization of these codes and categories from both SQ1 and SQ2.

Figure 13

Theme D: Codes and Categories with In-Vivo Examples

Finally, six students reported that there were no changes in their approaches to problem solving after practicing creative problem-solving strategies. However, it may be worth noting that five out of these six students did indicate using different approaches on their pre- and post-survey responses to SQ1, so it may be possible that they have not fully recognized changes they have made.

Student Work Samples with Regard to Metacognitive Regulation

To analyze the changes in students' metacognitive regulation after CCPI, I began to prepare for qualitative analysis of the PSTs and student work samples from the intervention. I started by deductively coding the template I designed for students PST exercises. I did this to identify the areas of the task where I determined a connection to different domains of metacognitive regulation, by assigning the codes "planning," "monitoring," and "evaluating" to the appropriate sections of the PST template and corresponding rubric items (see Appendix I). With multiple sections then labeled within each domain, I went through these codes again inductively using process coding to assign subcodes beneath each initial code. Since metacognitive regulation involves "the actions we take in order to learn" (Stanton, 2015, p. 2), I used process coding, sometimes called action coding, as a coding method, as it "uses gerunds ("-ing" words) exclusively to connote action in the data" (Charmaz, 2002 as cited in Saldaña, p. 143). Table 13 shows the sections of the PST that were coded and subcoded as described.

Table 13

Codes and Subcodes Assigned to Metacognitive Sections on PST Template

Item	Process subcode	Section on PST
		Planning
1p	Dissecting given information	Markup the text; identify the problem, familiar information, important information, and points of confusion.
2p	Examining current understanding	Connect information from the problem statement and your own knowledge to the scenario presented
3p	Identifying unknown information	What information do you still need to know or figure out?
4p	Brainstorming and organization	Writing or drawing ideas for constructing your argument
		Monitoring
1m	Exploring own understanding	Create/explore/explain to analyze your own understanding of connections
2m	Assessing own understanding	Do you have all the information you need to design a solution to this problem?
3m	Analyzing own critical reasoning	Explain why your solution is effective using evidence to support this
4m	Assessing own reasoning	Does your solution reasonably address the problem?
5m	Explaining possible shortcomings	Explain why it may not and/or where you may be able to go back or went back to make changes
		Evaluation
1e	Analyzing navigation through challenges	Describe one challenge you had in solving this problem and explain how you worked through it
2e	Justifying solution choice	If you came up with multiple possible solutions, describe why you determined that your chosen solution was the most effective
3e	Reflecting on alternate approaches	Look back on your work and explain something you could have done to solve this problem differently

After assigning the above subcodes, I wanted to look at student performance in the sections represented by each subcode by qualitatively coding student work samples from the third and fourth PSTs, both of which were completed independently after engaging with one teacher-led task, and one task completed in pairs or small groups. For this analysis, I wanted to narrow the amount of data I analyzed, while doing my best to maintain a representative sample of student performance in the data. To do so, I organized the 33 students by their average scores on PST 4 and split them into three groups according to the highest scoring, middle scoring, and lowest scoring students. I filtered out students who had not completed both PST 3 and PST 4 and then randomly selected 3 students from each group for analysis using a random number generator. This process resulted in 9 students whose work samples I analyzed across their two independent PSTs as a representation of students' metacognitive regulation. In total, I analyzed 18 student PST work samples. As all students used the same PST templates, and most students completed all sections, I decided to put an emphasis on *how* they engaged, rather than whether they engaged in the work using magnitude coding to code the student work samples. Magnitude coding, sometimes called value coding, can be used to add a supplemental symbolic code to indicate the intensity or evaluative content of data, and can supplement qualitative data by providing a numeric dimension for quality, strength, or value (Saldaña, 2021, p. 115). I began to deductively code the students' work using the subcodes I had created earlier and added a magnitude code "T" to data that demonstrated a thorough level of engagement through their responses, and "L" to data that demonstrated a limited level of engagement. Table 14 illustrates the results of the magnitude coding for each of the 9 students, on both PST 3 and PST 4.

Table 14

Frequency of Magnitude Codes from Qualitative Analysis of Student Work

Item	Subcode	Magnitude code frequency			
		PST 3		PST 4	
		L	T	L	T
	Planning				
1p	Dissecting given information	5	4	2	7
2p	Examining current understanding	7	2	4	5
3p	Identifying unknown information	6	3	3	6
4p	Brainstorming and organization	4	5	4	5
	Monitoring				
1m	Exploring own understanding	6	3	6	3
2m	Assessing own understanding			1[a]	
3m	Analyzing own critical reasoning	7	2	4	5
4m	Assessing own reasoning	4	5	5	4
5m	Explaining possible shortcomings	2[a]			
	Evaluation				
1e	Analyzing navigation through challenges	9	0	3	6
2e[b]	Justifying solution choice	3	5	4	2
3e	Reflecting on alternate approaches	7	2	7	2

[a]These sections were analyzed differently and are explained below
[b]Only six out of nine students completed this section on PST 4

Findings: Student Work Samples with Regard to Metacognitive Regulation

Through my qualitative analysis of the 18 student work samples, I was able to observe some outcomes and insights for each of the three aspects of metacognitive regulation. Out of the 10 sections on the PST that I coded for metacognitive regulation, student work improved in five and remained consistent in three. There were also two sections where student work declined slightly between PST 3 and PST 4. Table 15 organizes the subcodes by improvement.

Table 15

Metacognitive Regulation Subcoding by Level of Improvement

Item	Subcode	Domain
	Improvement	
1p	Dissecting given information	Planning
2p	Examining current understanding	Planning
3p	Identifying unknown information	Planning
3m	Analyzing own critical reasoning	Monitoring
1e	Analyzing navigation through challenges	Evaluating
	No Change	
4p	Brainstorming and organization	Planning
1m	Exploring own understanding	Monitoring
3e	Reflecting on alternate approaches	Evaluating
	Decline	
4m	Assessing own reasoning	Monitoring
2e	Justifying solution choice	Evaluating

Planning

Of the three stages of metacognitive regulation, students appeared to demonstrate their strongest work and largest improvements in the area of planning. The planning stage "involves the selection of appropriate strategies and the allocation of resources that affect performance" (Schraw, 1995, p. 354).

Dissecting given information. Students dissected information on the problem tasks by marking up the problem statement. This included identifying the problem, information that they already know, information important to the problem statement, and words or ideas that they are unsure of and would like to learn more about. All students whose work I analyzed accomplished this to varying degrees. I used the 'thorough level of engagement' code when students demonstrated clear differentiation between what was essential to the problem and what was not, and there was a noticeable improvement in the thoroughness of their dissection between PST 3 and PST 4.

Examining current understanding. Students examined their current understanding of the problem and the associated context by indicating what information they knew after reading the problem statement and connecting it to their own knowledge of the scenario presented. I coded student work with a 'thorough level of engagement' when the student not only identified key information from the problem statement, but also made connections that were not explicitly stated and/or incorporated their prior understanding of the topic. In the samples analyzed, the thoroughness of engagement increased between PST 3 and PST 4.

Identifying unknown info. Students identified unknown information by indicating what they thought they needed to know or figure out, what they may be wondering about, or what they needed to ask or discover to solve the problem. I coded student work as a 'thorough level of engagement' when the student went beyond simply restating the problem and demonstrated a more thoughtful approach indicative of their understanding, curiosity, and ability to ask meaningful questions. In the samples analyzed, the thoroughness of engagement increased between PST 3 and PST 4.

Brainstorming and organization. Students demonstrated their brainstorming and organization skills through words and drawings, including sketches, mind maps, and charts. Students were encouraged to diversify their thinking and illustrate their reasoning with multiple approaches for addressing the problem. I used the 'thorough level of engagement' code on student work that demonstrated logical and advanced reasoning skills consisting of a diverse array of original ideas and extended considerations for those ideas. Student performance on this section was consistent between PST 3 and PST 4.

Monitoring

Metacognitive monitoring refers to one's own "awareness of comprehension and task performance" (Schraw, 1995, p. 355). The sections of the PST I analyzed for metacognitive monitoring were areas where students were given opportunities to analyze and assess their own understanding, reasoning, and performance. Three of these five sections related to a "checkpoint" question, where students were asked to stop and assess either their understanding or their reasoning. The remaining sections of the template that I looked at for evidence of monitoring asked students to explain their understanding and reasoning.

Exploring own understanding. Students explored their own understanding by connecting information to organize their knowledge and demonstrate their comprehension. For example, in PST 3 students had to be able to recall how to map out a food web and illustrate the flow of energy through the organisms described in the problem statement. Additionally, they had to explain what effect the introduction of an invasive species would have on the other members of the ecosystem illustrated by their food web. In PST 4, students had to use evidence from the problem statement to explore the relationships and events occurring in the ecosystem described. Additionally, they had to make a graph, energy diagram, chart, or other representation to organize and evaluate the information they know so far. I used the ‘thorough level of engagement’ code where students were able to utilize previously learned skills to illustrate and organize their understanding, connect information from the problem and their own knowledge, and establish logical representations of their comprehension. Student performance on this section was low, however consistent between PST 3 and PST 4.

Assessing own understanding. Students assessed their own understanding after exploring it by answering a metacognitive checkpoint question. This question asked students if, after exploring their understanding, they had all the information that they needed to design a solution to the problem presented. Students had the option of checking yes, no, or maybe in response to this question. If they selected yes, students were instructed to move on to the next section. If they selected maybe, they were asked to review the information again, add anything that they thought was missing, and indicate what they added. If they selected no, they were asked to determine what they thought they may be missing and try to find this information or ask for support before moving on. Most students on both PST 3 and PST 4 selected yes and moved on, with only 1 student selecting maybe out of the samples analyzed. However, this student did not indicate that they added any information after assessing that they may need to. This section was particularly challenging to analyze because, although it was an opportunity for students to stop and monitor their own comprehension, I could not accurately determine if they actually did have the information they needed, if they simply thought they did, or if they did not know if they did, and marked yes just to move on. While all students did respond to this question, it was difficult to determine whether they actually paused to assess their understanding.

Analyzing own critical reasoning. Students analyzed their own critical reasoning by completing a claim, evidence, reasoning (CER) chart after ideating and determining their solution. Students were asked to state their claim for their answer to the question, provide the evidence that supports their claim, and then use their evidence and understanding to express reasoning for why their solution or conclusion was the most reliable or effective. The term "Meta-Reasoning" is a framework developed by Ackerman and Thompson (2017) that refers to the processes that monitor the progress of our reasoning and problem-solving activities. Therefore, for this analysis, I assessed the "reasoning" section of the CER chart as an assessment of metacognitive monitoring. I used the 'thorough level of engagement' code on this section when students were able to develop thorough reasoning for a solution that sensibly addressed the problem and rationalize how their evidence supported their solution. Student analysis of their own critical reasoning became more thorough between PST 3 and PST 4.

Assessing own reasoning. Students assessed their own reasoning from the previous section by again answering a metacognitive checkpoint question. This question asked students if, after providing and supporting their solution, their analysis reasonably addresses the problem presented. Students had the option of checking yes, no, or maybe in response to this question. If they selected yes, students moved on to the next section. If they selected maybe, they were asked to explain where they could go back and make changes or indicate if they went back and made changes. If they selected no, they were asked to explain why they thought so, and ask for support before moving on. Unlike the last metacognitive checkpoint, I did analyze this one by magnitude coding for a 'thorough level of engagement' or 'limited level of engagement.' Based on the reasoning that students provided for their conclusions and solutions in the previous question, I determined whether their responses of yes, maybe, or no indicates with accuracy whether the problem had been reasonably solved or addressed. Of the nine student samples analyzed, two out of nine students indicated “maybe” on PST 3, while the remaining seven indicated “yes.” In my analysis, I determined that both students who indicated maybe and three of the seven who indicated yes demonstrated an accurate self-assessment, for a total of five. On PST4, all nine students indicated “yes”, and I determined that only four of them demonstrated an accurate self-assessment of their work. Students struggled in their ability to assess their own reasoning as their ‘level of engagement’ became more limited between PST 3 and PST 4.

Explaining possible shortcomings. Students who indicated a response of “maybe” or “no” on the last question had the opportunity to explain why they thought their solution may have fallen short. As previously stated, of the nine student work samples analyzed, only two indicated a response of “maybe” on PST 3, and none on PST 4. The remaining students on each task indicated an answer of “yes.” The two students who indicated that their solution “might” reasonably address the problem both stated a reason for why they believed so, but neither provided an explanation as to where they could go back and make the appropriate changes, nor did they indicate they had gone back and attempted those changes. Although these students had, in my analysis, accurately identified that their solution may not fully or reasonably address the problem, they seemed to struggle with a thorough explanation for why this might be so. While only two work samples provided insight into this area of metacognitive monitoring, it demonstrates an area needing improvement in classroom practice and student performance.

Evaluating

Metacognitive evaluation refers to “appraising the products and regulatory processes of one’s learning” (Schraw, 1995, p. 355). The sections of the PST I attributed to evaluation all come from the “reflect” portion of the CCPP and give students the opportunity to look back on their own perseverance, solutions, and decision-making abilities.

Analyzing navigation through challenges. Students analyzed how they navigated challenges by describing one challenge they had in solving the problem and explaining how they worked through it. I used the ‘thorough level of engagement’ code when students were able to identify and describe a challenge that they encountered, and clearly articulate how they handled that challenge. In the samples analyzed, this area saw the greatest improvement in thoroughness between PST 3 and PST 4.

Justifying solution choice. In this part of the PST, students began by indicating if they had come up with multiple possible solutions to the problem. Students who came up with multiple possible solutions and chose one for their final reasoning were given the opportunity to justify their solution and explain why they chose it out of the options they had ideated. I used the ‘thorough level of engagement’ code when students were able to thoroughly explain how they chose their solution and explain the rationale behind their process. On PST 3, eight out of the nine students whose work I analyzed had in fact produced multiple options for their solutions, and all nine correctly indicated that they did. I coded five of the eight samples that had multiple solutions with a ‘thorough level of engagement' in the justification of their chosen solution. On PST 4, eight out of the nine students had also produced multiple options for their solutions, however interestingly, only six of them correctly identified the fact that they had. Of these six, I only coded two samples with a 'thorough level of engagement' in the justification of their chosen solution. Students appeared to struggle in this area. I am unsure as to why two students who had clearly ideated multiple solutions indicated that they had not, however regardless of this, the number of students who were able to thoroughly justify their choice declined from PST 3 to PST 4.

Reflecting on alternate approaches. Students reflected on their work by explaining something they could have done to solve the problem differently, as the final question on each PST. I used the 'thorough level of engagement' code when students were able to examine their procedure and elaborate on alternative steps or outcomes. Student performance on this section was limited, however consistent between PST 3 and PST 4. While all students could state something they could have done differently, fewer explained how or why.

CHAPTER 5

REFLECT: DISCUSSION

A mixed methods action research study makes use of available quantitative and qualitative data to "build a rigorous, cohesive set of conclusions" (James, 2008, as cited in Ivankova, 2015, p. 51). As a teacher, my practice heavily involves the use of both types of data, particularly in guiding the planning, monitoring, and evaluation of my own instruction and of student work. Since I was conducting my action research study in my classroom, I decided both quantitative and qualitative data collection were imperative to studying my research questions, as teacher-researchers often "have to include student achievement data to augment classroom observations and qualitative narratives" (Mills, 2011 as cited in Ivankova, 2015, p. 51).

In this chapter, I explore the complementarity and integration of my quantitative and qualitative data to answer my research questions. Then, I connect the outcomes of my study back to my theoretical framework and existing research. Finally, I explore the limitations of my study and discuss the implications for my practice and for future research, closing with a reflection on personal lessons learned.

Complementarity and Integration of the Data

I utilized a mixed methods concurrent triangulation design to collect, analyze, and interpret my data. Triangulating, or synthesizing, multiple sources of data helps a researcher to integrate large amounts of quantitative data with finer qualitative data to titrate their combined contribution (Ivankova, 2015), and is a powerful way to establish qualitative data credibility by cross-checking, or verifying the data (Mills, 2011 cited in Ivankova, 2015). I also maintained a practitioner journal throughout the course of this intervention, noting analysis of my construction of the Problem Solving Tasks (PSTs), assessment of student work, and observations of students' attitudes and approaches. I referred to these field notes to reflect on my own perceptions at the time of the study and incorporated those ideas into my final analysis. In the following sections, I discuss the complementarity between my quantitative results and qualitative findings while answering my research questions.

RQ 1: Changes in Students' Metacognitive Regulation

Research Question 1 asks "how and to what extent does students' metacognitive regulation change after their experience with Creative Cognitive Process Instruction?"

I derived insights regarding the changes in students' metacognitive regulation through my quantitative and qualitative analysis of PST criteria organized under the categories of planning, monitoring, and evaluating. I have found the quantitative and qualitative results demonstrate complementarity with one another.

First, I established that students' average scores on PST 4 were higher than their average scores on PST 3 for all three categories, planning, monitoring, and evaluating. I had previously determined that average scores for each PST as a whole had improved for students between PST 3 and PST 4, however, by grouping together and analyzing only the specific criteria regarding planning, monitoring, and evaluation, I was able to see that there was also an improvement in student performance specifically pertaining to metacognitive regulation in each of these domains. After further analyzing each criterion individually from each domain, I observed that student performance had improved most notably in five of the 10 criteria measured: 'dissecting given information', 'examining current understanding', 'identifying unknown information', 'analyzing own critical reasoning', and 'analyzing navigation through challenges.'

These results were consistent with the qualitative analysis of students' work on PST 3 and PST 4, for the same criteria: regarding planning, monitoring, and evaluating. The areas related to metacognitive regulation in which the random sample of nine students had demonstrated growth in their level of engagement with the problem task, were the same areas related to metacognitive regulation in which all student participants cumulatively improved their rubric scores between PST 3 and PST 4, with the most notable improvement seen in metacognitive planning. Table 16 illustrates the concurrence of student improvement in these areas from both analyses.

Table 16

Concurrence of Improvement in Metacognitive Regulation Through MMA

Most notable improvement in scores (quantitative analysis)[a]	Aspect of metacognitive regulation	Demonstrated a more thorough level of engagement (qualitative analysis)[b]
Dissecting given information	Planning	Dissecting given information
Examining current understanding	Planning	Examining current understanding
Identifying unknown information	Planning	Identifying unknown information
Analyzing own critical reasoning	Monitoring	Analyzing own critical reasoning
Analyzing navigation through challenges	Evaluating	Analyzing navigation through challenges

[a]Descriptive statistics based on analysis of 29 scores from students who completed both PST 3 and PST 4
[b]Analysis based on 9 randomly selected student work samples from the larger group

My qualitative analysis also determined that students showed consistent engagement on three and decreased engagement on two of the remaining five criteria. Although none of these areas saw a corresponding quantitative decline when rubric scores from all study participants were analyzed, the differences in scores between PST 3 and PST 4 for these criteria were much smaller.

Before introducing students to the Creative Cognitive Process Protocol (CCPP), I had asked them what was the first thing they should do when presented with a problem. I noted in my journal, students wanted to jump right into coming up with solutions, even when they did not understand the problem completely. After they finished PST 1, I noted students expressed that marking up the problem statement, defining unknown terms, graphing, mind mapping, and restating what they know were all beneficial. The significant increase in students' metacognitive regulation in the area of planning by the end of the intervention appears even more meaningful when contrasted with the observed lack of metacognitive planning in this area prior to the intervention. All four areas of metacognitive planning (in the student work samples assessed) saw more than 50% of students demonstrating a thorough level of engagement on PST 4, most notably in the areas of dissecting information, examining current understanding, and identifying unknowns where student planning specifically improved between PST 3 and PST 4, and a consistent performance in brainstorming and organizing ideas.

Although the quantitative analysis of PST scores for items under metacognitive monitoring improved considerably between PST 3 and PST 4 for participants as a whole, the student work samples I qualitatively analyzed illustrated students struggled in this area. Students made great strides in analyzing their own reasoning to justify their solution but fell short when it came to exploring their own understanding of the problem and assessing the strength of their reasoning for the solution they provided. The student work samples mostly fell to the side of lower engagement in these areas. These data and analysis help to pinpoint areas where students need additional instruction, support, and practice. Additionally, although the monitoring checkpoints that I incorporated into the CCPP did not yield enough data for a thorough analysis, I do feel that they are also indicative of areas for improvement, both in the instructional design of the intended monitoring opportunities, and in students' ability to practice self-monitoring of their own understanding and shortcomings. Although I did attempt to improve on the wording of these checkpoints between PST 2 and PST 3 after noticing that students overwhelmingly marked “yes” and moved on, I did not think that these checkpoints were ultimately effective in their intended goals, as much of the student work did not reflect the understanding that was being indicated with a “yes” response. I think that a better design or alternate approach could further engage students’ metacognitive monitoring abilities.

Finally, when it came to metacognitive evaluation, the section of the rubric addressing how students handled their own challenges improved substantially, as none of the student work samples demonstrated thorough engagement in this area on PST 3, however two-thirds did demonstrate thorough engagement on PST 4. While students increased their proficiency in this reflective exercise when identifying and explaining how they worked through things they struggled with, I did not see the same improvement when they were reflecting on the alternate approaches they could have used to solve the problem or justifying their choice for the solution that they did select. Although average PST rubric scores in the area of evaluation substantially increased on PST 4 for participants as a whole, this deeper analysis suggests that more practice with self-reflection may help support students in understanding their own choices and alternate approaches.

The implementation of Creative Cognitive Process Instruction (CCPI) has shown varying impact on students' metacognitive regulation in the three domains of planning, monitoring, and evaluating. Quantitative analysis of the corresponding PST rubric criteria illustrated improvement in student performance in each of these domains across PSTs, while qualitative analysis of student work from PST samples specified that the greatest improvement occurred specifically within the planning domain: dissecting information, examining understandings, identifying unknowns, and organizing their ideas. Additionally, students demonstrated enhanced capability in the monitoring domain (analyzing their own reasoning), and in the evaluation domain (analyzing how they navigated challenges). However, it was evident that certain aspects of monitoring and evaluation presented more challenges, indicating the need for further instructional support and practice to enhance self-monitoring and critical reflection abilities.

RQ 2: Changes in Students' Attitudes and Approaches to Creative Problem Solving

Research Question 2 asks "how and to what extent do students' attitudes and approaches to creative problem solving change after their experience with Creative Cognitive Process Instruction?"

I derived my insights regarding the changes in students' attitudes and approaches to creative problem solving after CCPI through my quantitative and qualitative analysis of the pre- and post-intervention attitudes and approaches survey, and my quantitative analysis of PST assessment scores. To answer RQ2, I bring together data and themes derived from student assessments of their own attitudes and approaches, along with my assessments of related problem-solving performance from graded PST work samples.

First, I established PST scores for all students significantly improved between both PST 2 and PST 4, and PST 3 and PST 4. This illustrates that through the CCPP, students were able to increase their proficiency toward creative problem solving as measured by the PST rubric, and that ultimately, they scored significantly higher on their final independent PST than their partnered PST and first independent PST attempts.

Mindset

When I analyzed and compared the students' open-ended responses between SQ1 and SQ2 on the pre- and post-intervention surveys, there was a pronounced shift in student attitudes toward task fulfillment, namely from giving up to persevering. Student responses in this area went from almost exclusively disposing of the task, to almost exclusively becoming more persistent, putting in more effort, and gaining fluency with problem solving. On the post-intervention survey, students also indicated reviewing their work to make sure their answers were reasonable. This distinct shift from trying to get done with the task to getting the task done well is complemented by the fact that all but one of the students whose comments fell under either "getting it done" or "getting it done well" also saw an improvement in their average PST scores over the course of the intervention. Analysis of the Likert questions on the attitudes and approaches survey did not quantitatively result in statistical significance between pre- and post- when participant responses were analyzed as one group, however, I believe that qualitatively, the students' own words provide a compelling argument for a pronounced positive shift in attitude, effort, and proficiency when it comes to the way they engage with solving problems.

Regarding student tendencies toward asking for support, in the qualitative data I saw a decline between pre- and post-intervention responses for SQ1 and only one mention of asking for help in SQ2. Although this portion of the data may indicate a positive trend toward students developing more self-sufficiency, it does diverge from the quantitative data in some interesting ways. Again, although analysis of the *attitudes and approaches* construct from the survey did not result in statistical significance between pre- and post- when participant responses were analyzed as one group, I did find significance in the area of seeking support when students were split into two groups; those whose responses became more "expert-like" or favorable, and those whose responses became less "expert-like" or less favorable when scored against the "expert-like" response answer key. Those whose attitudes and approaches became less favorable, agreed more often with the statement "If I'm not sure about the right way to start a problem, I'm stuck unless I ask for help" between pre- and post-surveys. Interestingly, however, the same group of students' PST rubric scores increased significantly between PST 2 and PST 4, and PST 3 and PST 4. This indicates that although these students' attitudes and approaches to problem solving became less favorable, and students believed they were stuck unless they asked for help, their performance on the PST 4 still showed a significant improvement over that of their previous two tasks.

Mindful Engagement

In addition to students' attitudinal shift resulting in them persisting through the process to get it done well, there were also several notable changes in student approaches to problem solving that emerged through my analysis. The most prominent change occurred in the many approaches students took to improve their mindful engagement with the PSTs.

One way students did this was by slowing down and engaging with the problem and their own thinking more deliberately. One of my intentions in creating the CCPP was to get students to think of problem solving as a step-by-step process, and to recognize the importance of understanding the problem before engaging with solution synthesis. The thoughtful deliberation that students described as a change in their approach after the intervention (on post-intervention survey SQ1 and SQ2) supports the idea that this aspect of the CCPP resonated with them and impacted the way they navigated problem solving. This idea was further strengthened by the statistically significant improvements that students made in the initial problem-solving steps of understanding and connecting, followed by their statistically significant improvement in synthesis.

Another way students demonstrated their mindful engagement with problem solving was through their adaptive use of strategic approaches. When asked about how their approaches to problem solving had changed after the intervention, student responses ranged from several ways of reframing the problem, to techniques for processing the information, identifying key concepts, and more. Regardless of the approaches they described, realizing that some adaptive strategy was necessary to effectively navigate and engage with the problem was a key takeaway. Again, as student PST scores significantly increased between the beginning and end of the intervention, this may quantitatively corroborate the idea that students' approaches were improving.

One of their adaptive techniques specifically centered around visual representation through drawings and diagrams. Interestingly, I found changes in *attitudes* *and approaches in* visual representation when I split the data into two groups, students whose responses became more “expert-like” or favorable, and those whose responses became less “expert-like” or less favorable. Students whose *attitudes and approaches* became more favorable agreed with the statement “I usually draw pictures even if there is no credit for drawing them,” while those whose *attitudes and approaches* became less favorable disagreed with the statement “I am equally likely to draw pictures and/or diagrams when answering a multiple-choice question or a corresponding free-response question.” From this analysis, students whose *attitudes and approaches* became more favorable were more inclined to choose to create visual aids as a part of their problem-solving process, and those with less favorable *attitudes and approaches* appeared more selective with when they might choose to do this. Regardless of this, however, all students were able to demonstrate some level of visual representation through drawings or diagrams on their PSTs where they were provided opportunities to do so.

Comprehension

Comprehension was another area where students indicated a change in their problem-solving approaches after the intervention. The techniques they found to be useful for understanding the problem involved reading and re-reading the problem statement and analyzing the context or situation within the problem. The qualitative analysis of these and other techniques being used for processing and comprehending information finds complementarity with my quantitative analysis of the “Understand” section of the CCPP. Interestingly, students' scores increased significantly between PST 3 and PST 4 in this section, but significantly decreased between PST 2 and PST 3 in the same section. It is possible this is indicative of a learning curve students experienced when transitioning from partner supported work to their first attempt at independent work, where scores significantly decreased, and then from their first to second attempt at independent work where their scores significantly improved. Ultimately, the emergence of comprehension techniques in their SQ2 responses, and the significant improvement in PST "Understand" scores provides strong evidence for a change in their approaches in this area.

Although the idea of conceptual bridging or connecting the problem to previously learned information or solutions was mentioned pre- and post-intervention in SQ1, it did not come through as a self-identified change in approach for students in SQ2. Conversely, however, average PST scores in the "Connect" section where students could utilize these strategies were significantly higher on PST 4 than they were on PST 2 and PST 3. This may indicate that while students' abilities to connect ideas together improved throughout the intervention, they may not have felt that this was necessarily a change for them, and instead something that they were already accustomed to doing while problem solving.

Divergent Thinking

Students who referenced a change in the way they analyze and consider solutions after the intervention demonstrated tendencies for divergent thinking and novel approaches to ideation. Their responses about producing many possible solutions and thinking outside of the box may have been influenced by the lessons on divergent thinking and mind mapping that they received as part of the CCPI, further demonstrated in the "Ideation" section of their PSTs. My quantitative analysis of this section supports the idea of growth in this area, but only does so significantly for the top scoring group between PST 2 and PST 4, based on their PST 4 scores. While the majority of students utilized the “Ideate” section to identify possible solutions to varying degrees, the convergence between quantitative and qualitative data in this area suggests that students who ultimately performed the best in this area were the ones who were able to achieve significant growth from partner supported work, and best developed their abilities for thorough independent ideation.

Regardless of the lack of quantitative significance for the other groups, participants as a whole scored significantly higher in the next section of the CCPP, “Synthesize,” where students were asked to choose and support their best solution. One student commented on SQ2 they now “balance divergent and convergent thinking,” shining a light on the development of approaches for solution synthesis which proved to increase significantly between PST 2 and PST4, and between PST 3 and PST 4.

Finally, student references to iterative problem solving did not show up when students were asked about a change to their approaches, which is likely the result of the CCPP not asking students to explicitly conduct multiple iterations of problem solving. However, the fact that conducting multiple and different attempts was brought up strongly in SQ1 is something to consider building on in future practice.

Relationship with Science

In addition to the Likert scale and free response questions on the pre- and post-intervention surveys, I also asked students to indicate if they liked or didn’t like science, and if they felt that they did well with science or struggled with it. I was interested in exploring if the intervention influenced students' attitudes towards science and their beliefs about themselves. Analyzing their responses between pre- and post-surveys and comparing them to their performance on the PSTs gave me several insights.

Students who indicated they enjoyed science prior to the invention were more likely to enjoy science and more likely to believe they do well in science after the intervention. However, these students were also more likely to believe they struggle with science than those who did not enjoy science, indicating that those who disliked science did not necessarily believe they were bad at it. Those who indicated they did not enjoy science before the intervention were also more likely to dislike it after the intervention, although, one-third of those who disliked science before the intervention indicated that they now liked science after the intervention. Regardless of the level of enjoyment indicated before the intervention, all students saw a statistically significant improvement in their PST 4 scores, indicating students may have been able to improve their attitudes and approaches toward problem solving despite their opinion of science.

Finally, both those who believed they did well and those who believed they struggled in science prior to the intervention were statistically more likely to maintain these beliefs after the intervention. Despite this, one third of those who indicated they struggled in science did change their mind to believe that they do well in science after engaging with the intervention. Students who indicated they do well in science pre-intervention and those who indicated they do well post-intervention both had statistically significant improvements in their PST 4 scores. Those who indicated that they struggled in science pre- and post- did not have statistically significant changes in their PST scores, however, of those who believed that they struggled pre-intervention, 67% improved their scores, scoring highest on PST 4.

The implementation of CCPI notably influenced students' attitudes and approaches to creative problem solving. Quantitative analysis of PST scores over time revealed significant improvement and enhanced proficiency in several problem-solving skills throughout the intervention. Qualitative analysis of students' attitudes toward task fulfillment indicated a considerable change from a mindset of giving up to one of perseverance, effort, and proficiency. Students demonstrated the shift from *getting it done* to *getting it done well* through several new and deliberate approaches, slowing down, engaging more mindfully with the problem tasks, and utilizing more strategy throughout. Strategies varied, but markedly fell into the categories of comprehension and divergent thinking. Comprehension strategies emphasized reading for understanding, context analysis, and visual representations. Divergent thinking strategies were used with most significant proficiency by top scoring students who developed skills for ideating independently, however all students significantly improved their performance quantitatively in the areas of solution synthesis. Ultimately, the goal of getting students to slow down and understand the problem before jumping into forming a solution was achieved, as indicated by the statistically significant improvements in understanding, connecting, and synthesizing. Although it appeared that the need for support decreased for students overall, those with less favorable *attitudes and approaches* determined they still felt stuck when beginning a problem, despite a significant improvement in their overall performance on the PSTs. Finally, the intervention had a positive impact on students' perceptions of science, with a slight increase in enjoyment and self-perceived competency, reinforcing the potential for influencing attitudes towards the subject despite initial preferences. Overall, the CCPI effectively promotes a transformative shift in students' attitudes and approaches, fostering a more creative and engaged problem-solving mindset.

Outcomes Related to Research and Theory

The theories that guided the design of my study lead me to a wealth of literature which I revisit here to connect my findings back to it. This literature also helped me understand where the challenges encountered in my personal context fit within the much larger discussion of educational challenges that have long persisted and are widely shared.

In research Question 1 I asked, "how and to what extent does students' metacognitive regulation change after their experience with Creative Cognitive Process Instruction?" To design an intervention that provided the space for students to engage with their metacognitive thinking, specifically metacognitive regulation, I needed to embed opportunities for planning, monitoring, and evaluating within my CCPP. I designed my CCPP with many thoughts in mind, one of which being the cognitive constructivist principle that learners actively construct their knowledge. Cognitive constructivism and metacognitive thinking come together when learners are conscious of that construction. By virtue of the constructive, personal, and strategic thinking involved in metacognition, it has largely been found to be amenable to classroom instruction (Paris & Winograd, 1990). Several studies have found that children who engage successfully in self-management are resourceful in trouble-shooting their problem solving, choosing appropriate goals, monitoring their own progress, and adjusting their effort and expectations accordingly (Paris & Winograd, 1990). For those reasons, many have concluded that “metacognition is part of adaptive learning and is useful to any domain of problem solving” (Paris & Winograd, p. 8, 1990).

In addition to its congruence with cognitive constructivist principles, the theory of metacognition was well suited for my study for its connections to creativity and social constructivist principles as well. Creativity has been attributed as a problem-solving ability by many researchers (Sternberg & Lubart, 1999, Runco, 2010 as cited in Jai et. al, 2019). Several studies have found that metacognitive training not only promotes but significantly improves creative problem solving, further supported by the research that found the brain regions which are activated for creative thinking overlap with those activated for monitoring (Jia et. al, 2019). Finally, building on Vygotsky’s socially mediated learning theory, Paris and Winograd (1990) support the idea of metacognition as a cognitive variable for social exchange, as the self-appraisal and self-management prompted by it can be promoted through others as well as through self-discovery. In this way, social interaction can be a catalyst for internalizing metacognitive strategies and applying them autonomously.

In their study, Hargrove and Nietfeld (2015) found explicit metacognitive instruction was necessary to improve problem-solving performance in students, and teachers can promote their students' metacognitive awareness by using mental models that increase students’ regulation of their own cognition. Providing explicit instruction through my CCPI and utilizing my CCPP model, I observed this to be true in my own findings. Problem-solving performance increased significantly across PSTs when all CCPP criteria were included in the analysis and increased across PSTs when the specific criteria for the domains of planning, monitoring, and evaluation were analyzed. Although there was a quantitative improvement in these three domains, qualitatively it was clear that students made greater strides in planning and found the areas of monitoring and evaluation to be more of a challenge. Similarly, in their study of metacognition and self-regulation in young students, Stephanou and Mpiontini (2017) found that of the three domains, students mostly applied planning while using evaluation the least. While my findings are inconclusive as to *why* this was the case, Stephanou and Mpiontini (2017) cite studies that suggest the ability for planning matures faster than the abilities for monitoring or evaluation, and that results such as these may indicate that students are not often asked to evaluate their own achievement.

In research Question 2 I asked, “how and to what extent do students’ attitudes and approaches to creative problem solving change after their experience with Creative Cognitive Process Instruction?” I designed the PSTs to build on students' existing schemas for problem solving with the hope that they could associate and assimilate the components of the CCPP to redesign those schemas. I had noted previously that prior to the intervention, my students were overwhelmingly quick to jump into coming up with solutions when presented with a problem, and that they normally moved on to problem solving even when they did not fully understand the problem. A study of New Zealand science students (Gunstone, 1991) also found that students had these transmissive perceptions of problem solving. Students were too concerned with getting the right answer rather than engaging with the process toward getting the answer. Their lack of understanding the purpose of what they were doing impacted their conceptions and attitudes toward problem solving and a lack of metacognition in their mental regulation and control (Gunstone, 1991).

Piaget's cognitive constructivist theory asserts that learners actively construct knowledge rather than passively take in information. I wanted my PSTs to align with this cognitive learning theory, offering students an "authentic task" (Bay et al., 2012) where they were responsible for actively problem solving after receiving initial input through a problem statement. It was also important that there was not just one correct answer, providing opportunities for students to practice divergent thinking, as it "represents the potential for creative thinking and problem solving" (Runco, 2014, p. 400) due to the novel ideas that can be produced.

My qualitative analysis of student self-perception of changes in attitudes and approaches to problem solving showed that after the CCPI intervention, they took a slower and more deliberate approach, engaging more mindfully with the problem task through several strategic approaches. Several of these strategic approaches fell under the umbrella of comprehension, including reading and re-reading for understanding, engaging in context analysis, and creating visual aids for understanding. While average PST scores in my study improved significantly over time, the CCPP components "Understand," "Connect," and "Synthesize" also specifically saw significant improvement across tasks. In a 2008 study by Lee, Chai and Teo, students were given 'ill-structured' problems that had divergent or alternative solutions. The results of this study showed that students who had gone through this problem-solving activity achieved a better conceptual understanding of the science concepts used in the problem (Lee et al., 2008). They concluded that their findings "might indicate the value of immersing students in a problem-solving environment as it gave them opportunities to make conscientious efforts to detect their conceptual deficits and reconcile their understanding, bringing them to a higher level of cognition" (Lee et al., 2008, p. 886). I also see the value in engaging students through problem solving and believe the significant improvement in the "Understand" and "Connect" sections of the PSTs in my study, along with students self-described improvements in their comprehension skills, may corroborate a similar pipeline between problem solving and improved understanding.

Although my situated context specifies arts integration, creativity really goes beyond that, representing a cognitive process through which non-standard and novel approaches are taken. Runco (2014) suggests the best estimate of one's potential for creative thinking can be derived from the ability for divergent thinking. Therefore, having students solve problems that did not have just one correct answer was important in developing their ability to produce numerous and varied responses to open-ended tasks. After producing these diverse ideas, students found the best or most reasonable solution through convergent thinking. The interaction of this "generation of novelty via divergent thinking and… evaluation of novelty via convergent thinking" (Cropley, 2005, p. 406-407) is important to the conceptualization of creativity (Jia et al., 2019). As I reflected on my practitioner journal, I was reminded of a moment during our whole class discussion and feedback after PST 3 where my students were debating the idea of "ridiculous solutions." For example, in PST 3, Kokanee salmon could not feed on Mysis shrimp because they stayed at the bottom of the lake during the daytime, while the salmon swam near the surface feeding. One student asked if their "ridiculous solution" of "tarping" (placing a tarp over) the whole lake to make the shrimp think it was nighttime so they would swim to the surface was okay. This sparked a lively debate around "ridiculous solutions," and we collectively decided that if you could provide evidence and reasoning, no solution is too "ridiculous." I think back to this moment because I appreciated the ways in which my students debated and considered novelty in their divergent thinking in such a passionate way.

As I mentioned earlier, in addition to the CCPP components "Understand" and "Connect," the "Synthesize" component also saw significant improvement in student scores across tasks. Student performance in the "Synthesize" component may be indicative of their convergent thinking skills, as this is where they indicated and provided reasoning for their chosen solution. Looking at this components place in the CCPP sequence, I also see a logical connection between student accomplishment in establishing reasonable solutions, and the significance of their progress in comprehension via the "Understand" and "Connect" components.

Apart from comprehension, divergent thinking was also another emergent qualitative category when students were asked about what changed in their problem-solving approaches after the intervention. Although performance in the "Ideate" component did not yield significant quantitative results when all student participants were considered, there was a significant improvement between PST 2 and PST 3 for the group that scored highest on PST 4. This illustrates that the students who scored highest on their final independent PST made the most significant improvement in their ability to ideate when transitioning from peer supported work to independent work. Lev Vygotsky's social constructivist theory argues that learning is a social and collaborative activity where meaning is created through interactions between people (Schreiber & Valle, 2013). I designed my CCPI to utilize Jerome Bruner's concept of scaffolding, or providing temporary assistance to aid students in mastering new skills and concepts (Structural

Learning, 2021) by starting with whole class, instructor guided practice on PST 1, and then collaborative work with partners in PST 2 before weaning students away from guidance and moving on to independent work on PST 3 and PST 4. As an extension of the social constructivist theory of learning, "when students are provided with support while learning a new concept or skill, they are better able to use that knowledge independently" (Structural Learning, 2021, para. 17). My goal in scaffolding support this way was to encourage a shift in students' Zone of Proximal Development, hopefully increasing what they can do without support.

There were some promising indicators of the potential success of this strategy. Quantitatively, average PST scores for the participant group, as a whole, saw a significant improvement between the supported task (PST 2) and the final independent task (PST 4) as well as between the two independent tasks (PST 3 and PST 4). Additionally, through qualitative analysis of student survey responses, there were less instances of students indicating that asking for help was one of their problem-solving approaches after the intervention. The congruence of less students feeling the need to ask for help along with increased proficiency in PST scores as students moved away from support bodes well for the idea that a scaffolded approach to support, informed by social constructivist theory, can aid students in feeling more competent and performing better, therefore contributing to a shift in students ZPD. While those whose attitudes and approaches became less favorable after the intervention indicated if they did not know how to start a problem, they feel stuck unless they ask for help, their PST scores also improved significantly between PST 2 and PST 4, and PST 3 and PST 4. This analysis may also shed some light on how students' attitudes may impact their awareness of their development and abilities when engaging with active learning and new skills through constructivist principles.

The most promising and pertinent shift in students' attitudes toward problem solving was from the idea of task disposal or just getting it done, to the emergence of perseverance, effort, and proficiency which is more indicative of getting it done well. Zimmerman and Campillo (2003) explain that "having knowledge and skill does not produce high-quality problem solving if people lack the self-assurance to use these personal resources" (pp. 221-22). Therefore, these feelings of tenacity and self-assurance that emerged post-intervention may positively correlate with the significant improvement in students' problem-solving abilities. In their study, Wismath, Orr and Zhong (2014) observed students' problem-solving skills after taking a course designed to develop them. They found that "confidence and self-efficacy are predictive of persistence and effort in problem solving" (Wismath et al., 2014, p. 5) and saw perceived skill acquisition in their students, with one noting "I got more strategic, more efficient, and more successful" (Wismath et al., 2014, p. 5). An interesting similarity between their study and mine, neither specifically asked students about their level of confidence after the interventions, however both saw instances of students spontaneously providing reflections that expressed comparable feelings toward improved self-assurance.

Overall, the scaffolded nature of support through the CCPI effectively promoted a transformative shift in students' attitudes and approaches toward problem solving, allowing them to associate and assimilate new ideas into their existing schema, enhancing their metacognitive regulation, and fostering a more creative and engaged problem-solving mindset.

Limitations

The nature of action research allows practitioner scholars the opportunity to critically examine their own practice, identify a problem, and work toward a solution. As such, limitations in action research studies often exist by virtue of the situated context, in my case, conducting research within the classroom setting and working with young students. One limitation in my study was the number of participants. Working with research participants under the age of 18 necessitated that I receive parental consent first, before seeking student participation. To do this, I reached out to parents with consent forms and explained the study and my role as a researcher, subsequently sending out assent forms to students for whom parental consent had been granted. Although I did my best to ensure that I would have enough participants for this study by following up with reminders, there were many parents who simply did not respond at all, and many students whose parents did provide consent that did not respond either. Ultimately, of the 92 students I had during the semester of my study, 55 received parental consent and 33 of those provided their own assent to participation.

According to district policy, surveys pertaining to research had to be taken by students outside of instructional time. This meant I had no control over whether students would take the surveys. I attempted to mitigate this by providing reminders, but eventually the last day of school arrived and only 28 of the 33 students who had completed the pre-survey completed and submitted the post-survey. Ultimately, this meant that I had about 15% less survey data than anticipated to analyze quantitatively and qualitatively regarding the attitudes and approaches to problem solving survey. The PSTs were completed during instructional time, so I was able to provide ample time for most students to complete them. Limitations in this regard occurred when some of the students in the study were absent from school or did not complete their tasks. For those who were absent, I was able to have them complete the tasks on alternative days when they were present, and for those who simply needed more time, I provided more time. For the few that seemed uninterested in completing their tasks, I provided gentle encouragement to try their best, ultimately ending up with 29 out of 33 students completing all three PSTs. When I had to conduct analysis that considered those who completed the intervention in full (both surveys *and* all 3 PSTs), that number dropped to 26 of 33, or 21% less data than I could have potentially had.

While it is unclear whether having the full participation of all who assented to the study would have changed the outcomes of my analysis, or if and how having more students in the study itself would have changed the outcomes, I feel as though I was able to collect enough data to gain insight into my research questions. The data I was not able to utilize as much as I would have liked came from the Likert scale questions on the pre- and post-surveys. I am not sure if having more responses would have provided more significant results, but this was also not the only limitation to the survey. The constructs I created were not reliable as arranged when I conducted reliability analysis. This led me to analyze 13 of the 14 survey items as one large construct instead, which made analysis more challenging, and showed no significant changes. I can see now that organizing and validating the constructs ahead of time, before using the survey for research purposes, would have allowed me to analyze the data regarding students' attitudes and approaches to problem solving differently. To mitigate this limitation, I chose to discuss some observations descriptively instead, and ultimately leaned more heavily on the qualitative data I collected from the surveys.

Finally, the short amount of time in which I conducted this study (approximately five weeks) may have also been a limitation. While in some ways, repetitive practice of new skills in quick succession may have helped students become more familiar and proficient with them, I also ran the risk of saturating students' engagement with the PSTs. I mitigated this by incorporating regular instruction, activities, and assignments throughout the intervention to maintain the authenticity of the classroom experience and keep students engaged. Additionally, conducting the CCPI intervention at the end of the semester/school year gave me a hard deadline for completion with little room for adjustment. Between spring break, state testing, safety drills, holidays, and other unpredictable occurrences, I had to remain flexible and consistently readjust my study implementation timeline. While I was able to incorporate the necessary adjustments, a longer time frame may have allowed for a more iterative approach.

Implications for Practice

Through the implementation of my CCPI intervention, and my lived experience as both a teacher and action researcher simultaneously, I have learned that a scaffolded and systematic approach to problem solving can promote a transformative shift in students' attitudes, approaches, and abilities, while fostering metacognitive regulation, and a more creative and engaged problem-solving mindset. The outcomes of this study suggest several implications for my situated context and for the facilitation of creative problem solving in classroom settings.

When I interviewed colleagues from my school site in cycle 0 of my research study, they talked about how problem-solving opportunities have been taken away from middle school students, whether by parents, teachers, curriculum, or technology. Without these opportunities, students are unable to feel confident in their abilities and often do not even know where to begin when presented with a problem. Supported by this notion and the findings from my study, I believe it is imperative teachers explicitly teach and model problem-solving strategies in the classroom, to encourage students to be active participants in the construction of their own knowledge, abilities, and metacognition. I also believe, when problem solving, the focus should be redirected from the end goal to the point of entry. It is possible that the student's tendencies to jump straight to solving the problem can be associated with the need or desire to solve the problem *correctly*. The findings from this study, specifically in the areas of comprehension and connection strategies, elucidate the need for teachers to de-emphasize the need for students to find the *right* answer, and instead, focus on helping students break down the barrier to entry so they may engage with the problem in a way that empowers them to understand it.

I believe this work also shows we should teach metacognition by attaching value to it. When I introduced my students to metacognition, none of them knew what the word meant or what ideas it represented, but they were curious. When I led a discussion with them about the domains of metacognitive regulation, they were engaged. When I asked them to choose their own, real-world scenario to practice planning, monitoring, and evaluating, they began constructing. By embedding these new skills into a context that was familiar and exciting (one they got to choose themselves), they were able to focus on the planning, monitoring, and evaluating aspects of problem solving, as opposed to struggling with understanding the content/context the problem was situated in. I believe a key part in getting students on board with learning skills like these relies on teachers helping them to understand that effective problem solving has purpose and value. If students see that purpose and value in things that they already enjoy, they may be less hesitant to transfer those skills when learning new curricular topics.

In season 4, episode 9 of *The Office*, Jim Halpert explains why he thinks it is odd that his boss, Michael Scott, is trying so hard to prove that he is creative because, as Jim puts it, "Michael actually might be the most creative person I've ever known. Every day, Michael says and thinks things that no one has ever said or thought before" (Novak & Reitman, 2007). In my eight years as an educator, I too have seen many students say and think things that no one has ever said or thought before without "trying" to be creative. While creativity is often tied to the arts, I think a broader, more accessible, and more accurate definition of creativity lies in these 'things no one has ever said or thought before;' novel and diverse approaches, thoughts, and ideas. It was a Monday morning, second period. PST 1 was projected on the smartboard in my classroom, and I had just asked my students to begin ideating their solutions for restoring balance to the jaguar and monkey populations described in the problem statement. We were working on this task collaboratively, so I asked for volunteers to share their ideas with the class as I scribbled them down on the projected copy. To move on to synthesis, we had to choose one idea from our class mind map to practice with. Hand after hand went up with students defending their choices, critiquing other options, and questioning unknowns until eventually the voices outnumbered the hands as the lively debate carried on. I remember watching and listening, so delightfully surprised at the impassioned convergence of creativity and critical thinking that was happening in the room. I believe the proficiency I observed in my students' engagement with divergent and convergent thinking through their PST work bears implications for how teachers merge creativity and critical thinking congruently, rather than treating them as two separate entities.

Through the guided and scaffolded approach I used for implementing the CCPI, I found that providing temporary support and progressively encouraging autonomy had a positive impact on student attitudes, approaches, and performance in problem solving. It is my assertion that when students are encouraged to become independent thinkers, and gain the confidence to do so, they demonstrate more effort and perseverance, achieve with more proficiency, and improve their confidence and beliefs about themselves. Since students in my study still accomplished significant improvements in creative problem solving even with less than favorable attitudes toward problem solving, science, and their own proficiency, I believe the design of the PSTs and the scaffolded model of learning proved to be transformative for students' abilities and warrant further enhancement for implementation in the classroom.

Finally, as a science teacher, I know the implications I have discussed apply to a science classroom, but I also believe the theories and findings from this study can have farther reaching implications in interdisciplinary contexts as well. In between PSTs, I carried on with regular classroom instruction, activities, and assessments within the same instructional unit. When grading one of their assessments, I noticed that students had started utilizing strategies that I had taught them through the intervention for problem solving. While this assessment was within the same instructional unit as the PSTs, I saw great promise for this internalization and transfer of skills and strategies. Therefore, my final implication for practice is that the notions of active knowledge construction, metacognition, creativity, and socially supported learning are not exclusive to the sciences, and I fully believe that problem solving is teachable and essential across a range of contexts.

Implications for Future Research

Action research is an iterative process, and so I believe that much could be gained from adjusting and then repeating this study in several iterations. Although I conducted this study over one curricular unit, future iterations could be done over a semester, school year or several school years. I believe that value can be derived from observing the outcomes of this intervention through varying instructional units, or even across completely different subject matters. Conducting iterations of this study would also likely help in further improving its design and effectiveness. Beyond the instructor conducting iterations of the intervention, students could also conduct multiple iterations of the problems presented in the PSTs. As I noted earlier in my analysis, students strongly referenced conducting multiple and different attempts in pre- and post-survey SQ1, however this approach did not show up at all when students were asked about changes to their approaches post-intervention in SQ2. This is likely the result of the CCPP not asking students to explicitly conduct multiple iterations of their problem solving and something that I believe could be built into the CCPP for future research.

Metacognitive regulation was one of the study's focal points I would also improve on for future research. While my findings regarding metacognitive planning were strong, I believe that the design of and/or approach to measuring monitoring and evaluation can certainly be improved upon in meaningful ways. Although I would redesign and refine sections in all three domains, I would particularly like to redesign the metacognitive checkpoints that I had embedded within the PSTs, as these proved to be a particularly weak point for gaining true insight into students' minds. Although many students marked 'yes' at these checkpoints and moved on, I did not feel as much of their work reflected the understanding that they were indicating with that 'yes' response. Therefore, I think that a better design or alternate approach could better engage students' metacognitive monitoring abilities. Additionally, although student self-efficacy was not a specific focus of my research, I think there may be an interesting intersection between student's self-perception and beliefs in their own abilities, and their ability to metacognitively regulate their mental processes. Some studies have shown a "positive and significant association between self-efficacy and metacognition" (Hayat & Shateri, 2019, p. 210) and so after seeing the slight change in student self-perception in this study, this could also be an interesting direction for future research.

As the teacher and practitioner, my dual role proved valuable in certain aspects however a challenge in others. While I firmly believe that as their teacher, I was best equipped to instruct and guide them through the intervention, I may have benefitted from having a more objective third-party assessment of their work, for example. Future iterations of this research could therefore have someone else grade student work samples, or even multiple graders to develop inter-rater reliability. Establishing this reliability would not only be beneficial in grading the PSTs, but also for strengthening the rubric itself.

Finally, I tackled many things at once in this study. While I have demonstrated the many ways in which the aspects of my research are interconnected, I also believe that independent studies on attitudes toward problem solving, approaches toward problem solving, and metacognitive regulation would all be appropriate and valuable for future research.

Personal Lessons Learned

Three years, and so many lessons learned. A recurring thought I had for the last three years was how much teaching is like action research. The more I learned about action research, identifying a problem, analyzing it, learning more about it, designing a potential way to address it, trying out your ideas, looking at your results, evaluating your findings, rinse, and repeat… the more I realized teachers conduct aspects of action research, informally and even unconsciously, in their practice every day. When I learned about action research and started to understand this process through a more formal, and more detailed lens, I learned the importance of what action researchers do, and confirmed the importance of what teachers do. The complementarity of teaching and action research lies in their reciprocal relationship. Teaching informs action research by providing real-world contexts and challenges. Action research enhances teaching by facilitating continuous improvement, innovation, and evidence-based decision-making in the educational process. A life-long student and problem solver by nature, I have sought to help students develop the tenacity for learning and the skills to effectively solve problems on their own. While there is still a long way to go, I believe that this work is a great paving stone along that path.

Creating takes time, trial, and error. Although this is a common truth, I was reminded of this in trying to create the PSTs for this study (and the study itself). I strove to align the PSTs with NGSS curricular standards, my CCPP, the domains of metacognitive regulation, creative opportunity, and the structure and approachability necessary for middle school students. It goes without saying that this took much longer, and many more tries than anticipated, as I created the PSTs through several designs, many sample problem tasks, multiple rounds of feedback, and a few readjustments as the study went on. Although it retained its intended essence, my intervention looked different at the end than what I envisioned at the beginning; and that is a good thing. The best idea is never the first idea. Great design takes time, and benefits from the wisdom gained through consistent effort.

Through this study I also learned the value of mixed methods research. As a teacher, I constantly had to evaluate student work, finding ways of assigning numerical scores to represent the depth of understanding demonstrated in assignments. In both the classroom and in research, quantitative data provides measurable insights into performance allowing for statistical analysis, while qualitative data offers a more nuanced understanding of thought processes, context, and motivation. In the classroom, providing qualitative feedback is essential for student growth and development in their comprehension, while the numerical scores determine the grade on the report card. I think in the traditional classroom setting, numerical data can overshadow the value of more nuanced, qualitative feedback and teachers and schools should utilize both more effectively. Although I found it to be a challenge at times with the diversity of data that I collected for this study, combining both types of data in my analysis helped me draw more comprehensive conclusions, balancing objective performance with the significance of student voice.

Speaking of the diversity of data that I collected, I also learned the importance of strategic alignment between research tools. Hindsight is 20/20 and until I engaged with the data analysis in my study, I was not able to recognize the areas where I could have strengthened the alignment between the components of my intervention. Had they been more aligned, there may have been areas where the data would have had more clear convergence/divergence and may have potentially resulted in more robust findings from the study. This also goes back to the value of time and iterations in developing the most successful tools and a piece of wisdom I will bear in mind.

Finally, Albert Einstein famously said "imagination is more important than knowledge. Knowledge is limited. Imagination encircles the world" (Albert Einstein, 1929). I do not think that Einstein was devaluing knowledge in this quote, I think he was simply illustrating that knowledge is not enough on its own. When imagination is allowed to flourish, I believe knowledge can transform into limitless bounds of understanding and innovation. Many things have changed over the course of my teaching career, but one thing that remained the same was how my students never ceased to amaze me with their insights, ideas, talents, and perspectives. Children are not short on imagination. I believe giving learners problem-solving tools and opportunities helps to create the environment for that imagination, and when given the environment for that imagination to bloom, they can accomplish anything. When I began my career in education eight years ago, I had no idea where it would lead me, but I never lost sight of my desire to make a difference. This research has given me the environment for my imagination to bloom, and this work is my symbolic step forward into the knowledge and understanding that I will continue to construct through my imagination.

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APPENDIX A

ASU IRB EXEMPTION

ASU Knowledge Enterprise Development

EXEMPTION GRANTED

Amy Markos
Division of Educational Leadership and Innovation - West Campus
602/543-6624
Amy.Markos@asu.edu

Dear Amy Markos:

On 10/27/2022 the ASU IRB reviewed the following protocol:

Type of Review:	Initial Study
Title:	Facilitating Creative Problem Solving in the Classroom
Investigator:	Amy Markos
IRB ID:	STUDY00016845
Funding:	None
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Documents Reviewed:	• El-Awar IRB protocol, Category: IRB Protocol; • IRB Requirement Statement, Category: Other; • IRB Revisions Letter, Category: Other; • Parent email, Category: Recruitment Materials; • Parental Consent Form, Category: Consent Form; • Student Assent Form, Category: Consent Form; • Supporting Documents, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions);

The IRB determined that the protocol is considered exempt pursuant to Federal Regulations 45CFR46 (1) Educational settings on 10/26/2022.

In conducting this protocol you are required to follow the requirements listed in the INVESTIGATOR MANUAL (HRP-103).

If any changes are made to the study, the IRB must be notified at research.integrity@asu.edu to determine if additional reviews/approvals are required.

Changes may include but not limited to revisions to data collection, survey and/or interview questions, and vulnerable populations, etc.

Sincerely,

IRB Administrator

cc: Nadine El-Awar
Nadine El-Awar

APPENDIX B

CALENDAR OF IMPLEMENTATION

CCPI Implementation Schedule

MARCH

M	T	W	TH	F
27 CONSENT REGULAR INSTRUCTION	28 CONSENT REGULAR INSTRUCTION	29 CONSENT REGULAR INSTRUCTION	30 CONSENT REGULAR INSTRUCTION	31 CONSENT REGULAR INSTRUCTION

APRIL

M	T	W	TH	F
3 SPRING BREAK	4 SPRING BREAK	5 SPRING BREAK	6 SPRING BREAK	7 SPRING BREAK
10 CONSENT ASSENT / PRE-SURVEY REGULAR INSTRUCTION	11 CONSENT ASSENT / PRE-SURVEY REGULAR INSTRUCTION	12 CONSENT ASSENT / PRE-SURVEY REGULAR INSTRUCTION	13 CONSENT ASSENT / PRE-SURVEY REGULAR INSTRUCTION	14 CONSENT ASSENT / PRE-SURVEY REGULAR INSTRUCTION
17 CONSENT ASSENT / PRE-SURVEY REGULAR INSTRUCTION	18 CONSENT ASSENT / PRE-SURVEY REGULAR INSTRUCTION	19 CONSENT ASSENT / PRE-SURVEY REGULAR INSTRUCTION	20 CONSENT ASSENT / PRE-SURVEY REGULAR INSTRUCTION	21 METACOGNITION
24 NO SCHOOL	25 CCPP	26 DIVERGENT THINKING	27 REGULAR INSTRUCTION	28 REGULAR INSTRUCTION

MAY

M	T	W	TH	F
1 STATE TESTING	2 REGULAR INSTRUCTION	3 STATE TESTING	4 REGULAR INSTRUCTION	5 PST 1
8 PST 1	9 REGULAR INSTRUCTION	10 PST 2	11 PST 2	12 REGULAR INSTRUCTION
15 REGULAR INSTRUCTION	16 REGULAR INSTRUCTION	17 REGULAR INSTRUCTION	18 FEEDBACK	19 PST 3
22 PST 3	23 REGULAR INSTRUCTION	24 FEEDBACK	25 PST 4	26 PST 4

JUNE

M	T	W	TH	F
29 NO SCHOOL	30 FEEDBACK	31 POST-SURVEY REGULAR INSTRUCTION	1 POST-SURVEY REGULAR INSTRUCTION	2 POST-SURVEY REGULAR INSTRUCTION
5 POST-SURVEY REGULAR INSTRUCTION	6 POST-SURVEY REGULAR INSTRUCTION	7 POST-SURVEY REGULAR INSTRUCTION	8 POST-SURVEY REGULAR INSTRUCTION	9 POST-SURVEY REGULAR INSTRUCTION

APPENDIX C

PRE- AND POST-INTERVENTION SURVEY

Attitudes and Approaches to Creative Problem Solving Survey

Survey Constructs	
	Motivation/determination when solving problems
	Divergent thinking: do students use multiple approaches to solve problems
	Ability to connect problems to existing knowledge
	Utilizing visual representation as a problem-solving strategy
	Reflection on their work

Please rate the following assessment items:

Motivation/Determination *Attitude toward beginning and/or continuing to solve a problem*		**Strongly Disagree**	**Disagree**	**Agree**	**Strongly Agree**
1.	If I’m not sure about the right way to start a problem, I’m stuck unless I ask for help	☐	☐	☐	☐
2.	If I cannot solve a problem in 10 minutes, I give up on that problem	☐	☐	☐	☐
3.	When I have difficulty solving a problem, I like to think through the problem with a peer	☐	☐	☐	☐
Divergent Thinking *Exploring many possible solutions or ways of thinking*		**Strongly Disagree**	**Disagree**	**Agree**	**Strongly Agree**
4.	There is usually only one correct way to solve a given problem	☐	☐	☐	☐
5.	I use a similar approach to solving all problems even if the problems are very different	☐	☐	☐	☐
6.	If I used two different approaches to solve a problem and they gave different answers, I would spend time thinking about which approach is more reasonable	☐	☐	☐	☐

7.	I try different approaches if one approach does not work	☐	☐	☐	☐
Connection to Existing Knowledge *How well can you use what you've already learned?*		**Strongly Disagree**	**Disagree**	**Agree**	**Strongly Agree**
8.	If I'm not sure about the correct way to solve a problem, I will think about concepts that may apply and see if they lead me to a reasonable solution	☐	☐	☐	☐
9.	When I solve problems, I always think about the concepts that relate to the problem	☐	☐	☐	☐
Visual Communication *Representing thoughts and ideas through images*		**Strongly Disagree**	**Disagree**	**Agree**	**Strongly Agree**
10.	When solving problems, I often find it useful to first draw a picture or a diagram of the situations described in the problems	☐	☐	☐	☐
11.	I am equally likely to draw pictures and/or diagrams when answering multiple-choice question or a corresponding free-response question	☐	☐	☐	☐
12.	I usually draw pictures and/or diagrams even if there is no credit for drawing them (on an assignment or test)	☐	☐	☐	☐
Reflection *Thinking back on the steps that have been taken*		**Strongly Disagree**	**Disagree**	**Agree**	**Strongly Agree**
13.	If I get an answer to a problem that does not seem reasonable, I spend time thinking about what may be wrong with the answer	☐	☐	☐	☐
14.	If I realize that my answer to a problem is not reasonable, I trace back my steps to see where I went wrong	☐	☐	☐	☐

Please answer the following question:

Pre-intervention: *[this question will be included on the pre-intervention survey]*

15.	Please describe your thought process when you encounter a problem that you do not immediately know how to solve

Post-intervention: *[these questions will be included on the post-intervention survey]*

15.	Please describe your thought process when you encounter a problem that you do not immediately know how to solve
16.	Please describe how your approaches to problem-solving have changed after practicing creative problem-solving strategies

Please answer the following questions about yourself:

Demographic Information:			
Gender:	**Female**	**Male**	**Non-binary**
	☐	☐	☐

How do you feel about science?	**I enjoy science & do well with it**	**I enjoy science but I struggle with it**	**I don't enjoy science but do well with it**	**I don't enjoy science & struggle with it**
	☐	☐	☐	☐

APPENDIX D

PROBLEM SOLVING TASK RUBRIC

Problem Solving Task Rubric

Exemplary 4	**Competent 3**	**Developing 2**	**Limited 1**
Component 1: Understand *Students make sense of information presented to them and understand the problem*			
Thoroughly identifies key information by marking up the problem statement	Identifies key information by marking up the problem statement	Identifies some key information by marking up the problem statement	Does not identify key information in the problem statement
*Explores knowledge gaps through thorough and accurate written explanation	*Explores knowledge gaps through written explanation	*Attempts to explore knowledge gaps with inaccurate explanation	*Does not explore knowledge gaps
Articulates the problem beyond what is explicitly given	Accurately identifies and states the problem	Identifies and/or states the problem inaccurately	Does not identify and/or state the problem
Demonstrates thorough understanding of task through written explanation	Accurately identifies the task through written explanation	Partially identifies the task and/or misinterprets the task through written explanation	Does not understand the task or provide written explanation
Component 2: Connect *Students make connections between their knowledge and the problem, explain the ideas and concepts they extracted*			
Incorporates information with personal insights relevant to the problem and/or task	Identifies sufficient information that is relevant to the problem and/or task	Identifies information, some of which is relevant to the problem and/or task	Does not connect problem to existing knowledge
Demonstrates advanced thinking through extended reasoning/questions regarding unknown information	Identifies important questions and unknown information that must be determined	Identifies insufficient and/or some irrelevant unknown information to determine	Does not identify the need to determine further information to address the problem/task
Establishes deep reasoning and explanation by connecting information and answering preliminary questions	Demonstrates logical reasoning and explanation by connecting information and answering preliminary questions	Provides some reasoning and/or explanation for connections and preliminary questions	Does not provide reasoning and/or explanation

from the problem statement			
*Effectively evaluates and enhances understanding if needed	*Evaluates and enhances understanding if needed	*Does not fully enhance understanding when needed	*Does not enhance understanding when needed
Component 3: Ideate *Students use relevant concepts to formulate ideas and develop possible solutions*			
Thoroughly represents and extends their ideation process through visual evidence	Demonstrates visual evidence of ideation	Some visual attempt at ideation	Does not visually represent any aspect of the ideation process
Demonstrates advanced reasoning, illustrating multiple possible approaches relevant to solving the problem	Illustrates logical reasoning and multiple possible approaches relevant to solving the problem	Indicates some reasoning and at least one possible approach to solving the problem	Does not provide evidence of reasoning or approaches to solving the problem
Develops advanced considerations for each possible solution	Includes some extended considerations for each possible solution	Attempts to include some further considerations for at least one possible solution	Does not include any further considerations for possible solutions
Component 4: Synthesize *Students apply facts, concepts, and ideas to establish and support their solution and evaluate their outcome*			
Produces a well-founded solution to the problem	Produces a reasonable solution to the problem	Produces a solution to the problem; may not be viable	Does not arrive at a solution to the problem
Thoroughly identifies evidence that support their solution	Provides some evidence that support their solution	Includes some evidence that may or may not support their solution	Does not provide any evidence that support their solution
Develops advanced reasoning rationalizing how the evidence supports their solution	Reasonably connects the evidence to their solution	Attempts to connect the evidence to their solution; does not support their claim	Does not connect the evidence to their solution
Accurately evaluates whether or not their final solution solves the problem	Indicates with some accuracy whether or not their final solution solves the problem	Struggles to recognize the accuracy or validity of their solution	Does not know what an accurate solution to the problem or question looks like

*Demonstrates a thorough analysis of possible errors	*Offers an accurate explanation for possible errors	*Attempts to indicate where an error may have occurred	*Does not attempt to provide an explanation
Component 5: Reflect *Students justify their conclusions and reflect on methods and challenges*			
*Identifies challenges and clearly articulates how they were handled	*Identifies challenges and reasonably explains how they were handled	*Attempts to identify challenges, does not articulate how they were handled	*Does not recognize that challenges were apparent; none identified
*Thoroughly explains how they chose their solution and rationale behind their process	*Offers a reasonable explanation of their process and choice of solution	*Attempts to explain their reasoning, but may be incomplete or lacking clarity	*Does not provide insight on their thought process
Examines their procedure and elaborates on alternative steps or outcomes	Explains where alternative steps or outcomes may exist	Indicates some alternative option, but does not explain it	Does not provide reflection on alternative steps or outcomes

*May not apply to all work samples

APPENDIX E

PROBLEM SOLVING TASK 1

MS-LS2-1: Ecosystems: Interactions, Energy and Dynamics

SEP	DCI	CC
Analyzing and interpreting data	Organisms and population size and growth are dependent on environmental interactions and access to resources	Cause and effect

PERFORMANCE EXPECTATION
Analyze and interpret data to provide evidence for the **effects** of **resource availability on organisms and populations of organisms in an ecosystem**.

Observable features of student performance:

1. **Organizing data**
    a. Students organize the given data (e.g., using tables, graphs, and charts) to allow for analysis and interpretation of relationships between resource availability and organisms in an ecosystem, including:
        i. Populations (e.g., sizes, reproduction rates, growth information) of organisms as a function of resource availability.
        ii. Growth of individual organisms as a function of resource availability.
2. **Identifying relationships**
    a. Students analyze the organized data to determine the relationships between the size of a population, the growth and survival of individual organisms, and resource availability.
    b. Students determine whether the relationships provide evidence of a causal link between these factors.
3. **Interpreting data**
    a. Students analyze and interpret the organized data to make predictions based on evidence of causal relationships between resource availability, organisms, and organism populations. Students make relevant predictions, including:
        i. Changes in the amount and availability of a given resource (e.g., less food) may result in changes in the population of an organism (e.g., less food results in fewer organisms).
        ii. Changes in the amount or availability of a resource (e.g., more food) may result in changes in the growth of individual organisms (e.g., more food results in faster growth).
        iii. Resource availability drives competition among organisms, both within a population as well as between populations.
        iv. Resource availability may have effects on a population's rate of reproduction.

Prior knowledge connection:

- **Populations:**
    - Limiting factors: a resource or condition that limits the size of a population (water, sunlight, food, space, etc…)
    - Carrying capacity: the largest number of organisms an ecosystem can support
    - Biotic potential: the highest rate of reproduction possible by a species in ideal living conditions
- **Relationships:**
    - Competition: organisms competing for the same resources (well adapted members are more likely to survive and reproduce)
    - Predation: populations change because of predator/prey relationships
        - Predators: animals that eat other animals
        - Prey: the animals being eaten (amount of prey is a limiting factor)
    - Cooperation: when members of a population cooperate to help each other survive
    - Symbiosis: organisms from different species interact with each other in a way that benefits one or both of them

Key vocabulary:			
Organism	Population	Habitat	Resource
Reproduction	Limiting factor	Carrying capacity	Biotic potential
Competition	Predation	Predator	Prey
Cooperation	Symbiosis		

PST #1 MS-LS2-1

Problem Statement:

You are a research assistant currently working with a team in a remote jungle habitat. During your first week on the job, you are given the following data and asked to analyze it for possible cause and effect relationships currently at play in the jungle. In this tropical rainforest ecosystem, the jaguar is the primary predator of the monkey. Both of their populations have been fluctuating over the past several years and something has caused them to no longer be in balance. The monkey's primary food source are the fruit trees that grow in this jungle region. Plant A is known to compete with these fruit trees for essential resources and growing space.

This table shows the population data for each species over the last several years:

Year	1	2	3	4	5	6	7	8	9	10	11	12
Monkeys	900	1050	900	600	675	750	675	600	510	420	360	300
Jaguars	200	220	250	450	200	170	225	250	225	250	300	400
Plant A	100	150	200	300	450	675	750	800	825	850	875	1000

Your task is to analyze and interpret the data provided to determine the cause of the changes to these populations, and design a solution to restore balance to the ecosystem. Pay close attention to the effects of resource availability on each population. Your solution should ensure that the populations of jaguars and monkeys are maintained at healthy levels.

UNDERSTAND ***Make sense of the information presented and understand the problem***
After reading the problem statement, go back and **mark up the text**. Identify the problem and highlight it. Place a checkmark (✓) next to anything that you have already learned. Underline information that is important to the problem statement. Circle words or ideas that you are unsure of their meaning. **Go back to your notes and re-familiarize yourself with any words or ideas that you circled. Write down definitions or ideas that you'd like to remember here:** **What is the problem? Identify and state it here:** **What are you being asked to do to solve it? State it here:**

CONNECT
Connect given information with prior knowledge and content understanding

What information do I know?	What information do I need to know or figure out?

Graph the data provided in the problem statement:
(don't forget to include a title, key and axis labels)

Use your graph to describe how this ecosystem has been affected:

What may have caused the problem?

Do you have all the information you need to try and solve this problem?

YES ☐ (move on to the next step)
MAYBE ☐ (review the information again, add anything that's missing)
NO ☐ (what do you think you are still missing? Try to find this info before moving on)

IDEATE *Map out your ideas for solving the problem*
Write or draw your ideas for solving this problem: (try sketches, mind maps, charts, etc…)

SYNTHESIZE *Form your solution*
Restate the problem given and what you are trying to solve: **Explain a possible solution to this problem:** **Claim** (What you think is the most effective or reasonable solution) — **Evidence** (Information that supports your claim) — **Reasoning** (Explanation of why and how the evidence supports your claim) **Does your solution make sense?** YES ☐ (great!) MAYBE ☐ (explain where you may be able to go back and make changes) NO ☐ (explain why)

REFLECT ***Evaluate your process and conclusion***
Describe one struggle you had in solving this problem and how you handled it   **Did you come up with multiple possible solutions to this problem?** YES ☐ NO ☐ **If YES, describe why you chose the solution that you did:**   **Describe one way you could have solved this problem differently**

APPENDIX F

PROBLEM SOLVING TASK 2

MS-LS2-1: Ecosystems: Interactions, Energy and Dynamics

SEP	DCI	CC
Analyzing and interpreting data	Organisms and population size and growth are dependent on environmental interactions and access to resources	Cause and effect

PERFORMANCE EXPECTATION
Analyze and interpret data to provide evidence for the **effects** of **resource availability on organisms and populations of organisms in an ecosystem**.

Observable features of student performance:

1. **Organizing data**
   a. Students organize the given data (e.g., using tables, graphs, and charts) to allow for analysis and interpretation of relationships between resource availability and organisms in an ecosystem, including:
      i. Populations (e.g., sizes, reproduction rates, growth information) of organisms as a function of resource availability.
      ii. Growth of individual organisms as a function of resource availability.
2. **Identifying relationships**
   a. Students analyze the organized data to determine the relationships between the size of a population, the growth and survival of individual organisms, and resource availability.
   b. Students determine whether the relationships provide evidence of a causal link between these factors.
3. **Interpreting data**
   a. Students analyze and interpret the organized data to make predictions based on evidence of causal relationships between resource availability, organisms, and organism populations. Students make relevant predictions, including:
      i. Changes in the amount and availability of a given resource (e.g., less food) may result in changes in the population of an organism (e.g., less food results in fewer organisms).
      ii. Changes in the amount or availability of a resource (e.g., more food) may result in changes in the growth of individual organisms (e.g., more food results in faster growth).
      iii. Resource availability drives competition among organisms, both within a population as well as between populations.
      iv. Resource availability may have effects on a population's rate of reproduction.

Prior knowledge connection:

- **Populations:**
  - Limiting factors: a resource or condition that limits the size of a population (water, sunlight, food, space, etc…)
  - Carrying capacity: the largest number of organisms an ecosystem can support
  - Biotic potential: the highest rate of reproduction possible by a species in ideal living conditions
- **Relationships:**
  - Competition: organisms competing for the same resources (well adapted members are more likely to survive and reproduce)
  - Predation: populations change because of predator/prey relationships
    - Predators: animals that eat other animals
    - Prey: the animals being eaten (amount of prey is a limiting factor)
  - Cooperation: when members of a population cooperate to help each other survive
  - Symbiosis: organisms from different species interact with each other in a way that benefits one or both of them

Key vocabulary:			
Organism	Population	Habitat	Resource
Reproduction	Limiting factor	Carrying capacity	Biotic potential
Competition	Predation	Predator	Prey
Cooperation	Symbiosis		

PST #1 MS-LS2-1

Problem Statement:

You are a research assistant currently working with a team in a remote jungle habitat. During your first week on the job, you are given the following data and asked to analyze it for possible cause and effect relationships currently at play in the jungle. In this tropical rainforest ecosystem, the jaguar is the primary predator of the monkey. Both of their populations have been fluctuating over the past several years and something has caused them to no longer be in balance. The monkey's primary food source are the fruit trees that grow in this jungle region. Plant A is known to compete with these fruit trees for essential resources and growing space.

This table shows the population data for each species over the last several years:

Year	1	2	3	4	5	6	7	8	9	10	11	12
Monkeys	900	1050	900	600	675	750	675	600	510	420	360	300
Jaguars	200	220	250	450	200	170	225	250	225	250	300	400
Plant A	100	150	200	300	450	675	750	800	825	850	875	1000

Your task is to analyze and interpret the data provided to determine the cause of the changes to these populations, and design a solution to restore balance to the ecosystem. Pay close attention to the effects of resource availability on each population. Your solution should ensure that the populations of jaguars and monkeys are maintained at healthy levels.

UNDERSTAND ***Make sense of the information presented and understand the problem***
After reading the problem statement, go back and **mark up the text**. Identify the problem and highlight it. Place a checkmark (✓) next to anything that you have already learned. Underline information that is important to the problem statement. (Circle) words or ideas that you are unsure of their meaning. **Go back to your notes and re-familiarize yourself with any words or ideas that you circled. Write down definitions or ideas that you'd like to remember here:** **What is the problem? Identify and state it here:** **What are you being asked to do to solve it? State it here:**

CONNECT
Connect given information with prior knowledge and content understanding

What information do I know?	What information do I need to know or figure out?

Describe the different kinds of relationships between the organisms in this coral reef ecosystem:

Predict how the problem you've identified may be impacting the relationships you've described above:

Do you have all the information you need to design a solution to this problem?

YES ▢ (move on to the next step)
MAYBE ▢ (review the information again, add anything that's missing)
NO ▢ (what do you think you are still missing? Try to find this info before moving on or ask for support)

IDEATE ***Map out your ideas for solving the problem***
Write or draw your ideas for solving this problem: (try sketches, mind maps, charts, etc…)

SYNTHESIZE ***Form your solution***
Restate the problem given and what you are trying to solve:
Explain a possible solution to this problem:

Claim (What you think is the most effective or reasonable solution)	**Evidence** (Information that supports your claim)	**Reasoning** (Explanation of why and how the evidence supports your claim)

Does your solution make sense?

YES ▢ (great!)
MAYBE ▢ (explain where you may be able to go back and make changes)
NO ▢ (explain why and ask for support)

REFLECT ***Evaluate your process and conclusion***
Describe one challenge you had in solving this problem and how you handled it   **Did you come up with multiple possible solutions to this problem?** YES ▢ NO ▢ **If YES, describe why you chose the solution that you did:**   **Describe one way you could have solved this problem differently**

APPENDIX G

PROBLEM SOLVING TASK 3

MS-LS2-3: Ecosystems: Interactions, Energy and Dynamics

SEP	DCI	CC
Developing and using models	Food webs are models that demonstrate how matter and energy are transferred between groups, and into or out of a system	Energy and matter

PERFORMANCE EXPECTATION
Develop a model to describe **cycling of matter and flow of energy among living and nonliving parts of an ecosystem.**

Observable features of student performance:

1. **Components of the model**
    a. To make sense of a given phenomenon, students develop a model in which they identify the relevant components, including:
        i. Organisms that can be classified as producers, consumers, and/or decomposers.
        ii. Nonliving parts of an ecosystem (e.g., water, minerals, air) that can provide matter to living organisms or receive matter from living organisms.
        iii. Energy
    b. Students define the boundaries of the ecosystem under consideration in their model (e.g., pond, part of a forest, meadow; a whole forest, which contains a meadow, pond, and stream).
2. **Relationships**
    a. In the model, students describe relationships between components within the ecosystem, including:
        i. Energy transfer into and out of the system.
        ii. Energy transfer and matter cycling (cycling of atoms):
            1. Among producers, consumers, and decomposers (e.g., decomposers break down consumers and producers via chemical reactions and use the energy released from rearranging those molecules for growth and development).
            2. Between organisms and the nonliving parts of the system (e.g., producers use matter from the nonliving parts of the ecosystem and energy from the sun to produce food from nonfood materials).
3. **Connections**
    a. Students use the model to describe the cycling of matter and flow of energy among living and nonliving parts of the defined system, including:
        i. When organisms consume other organisms, there is a transfer of energy and a cycling of atoms that were originally captured from the nonliving parts of the ecosystem by producers.

ii. The transfer of matter (atoms) and energy between living and nonliving parts of the ecosystem at every level within the system, which allows matter to cycle and energy to flow within and outside of the system.

b. Students use the model to track energy transfer and matter cycling in the system based on consistent and measurable patterns, including:
   i. That the atoms that make up the organisms in an ecosystem are cycled repeatedly between the living and nonliving parts of the ecosystem.
   ii. That matter and energy are conserved through transfers within and outside of the ecosystem.

Prior knowledge connection:

- **Ecosystem:** the living and nonliving factors that work together and interact in an area
  - **Biotic factors:** living and once-living parts
  - **Abiotic factors:** nonliving parts (air, water, soil, sunlight, temperature, climate)
- **Feeding relationships:**
  - **Producers:** (a.k.a. autotrophs) make their own food (produce their own energy)
  - **Consumers:** (a.k.a. heterotrophs) consume other organisms for energy
    - **Herbivores:** plant eaters (eat producers)
    - **Carnivores:** meat eaters (eat other consumers)
      - **Scavengers:** eat the remains of organisms left behind by other animals
    - **Omnivores:** plant and animal eaters
    - **Decomposers:** omnivores that eat dead organisms and other waste
    - **Chemotrophs:** get energy directly from chemicals without using the sun
- **Food chain:** shows where different organisms get their food
  - **Primary consumer:** producer
  - **Secondary consumer:** eats the primary consumer for energy
  - **Tertiary consumer:** eats the secondary consumer for energy
- **Food webs:** show all of the feeding relationships and overlapping food chains
- **Energy and matter cycles**
  - **Energy cycle:** energy is passed through ecosystems through food chains and food webs
    - Only about 10% of the energy from one level gets passed on to the next
    - An energy pyramid shows the energy at each feeding level of an ecosystem

Key vocabulary:

Ecosystem	Biotic factor	Abiotic factor	Producer
Consumer	Herbivore	Carnivore	Omnivore
Food chain	Primary consumer	Secondary consumer	Tertiary consumer
Food web	Energy cycle		

PST #3 MS-LS2-3

Problem statement:

Flathead Lake is a freshwater lake in Northwestern Montana. This lake is home to a variety of phytoplankton and other underwater plants that use abiotic factors to create energy to support the animal life in and around the lake. As settlers began to build towns around Flathead Lake in the early 1900's, they started stocking the lake with non-native fish in order to increase fishing. Among the several types of fish that were introduced were the lake trout in 1905, and the kokanee salmon in 1916. The kokanee salmon live at the surface of the lake, where they feed on their main food source, the zooplankton. The zooplankton feed on the phytoplankton. As the kokanee salmon population grew over the years, bears and bald eagles came to the area and thrived as consumers by feeding on the salmon population.

In order to try and grow their population further, fisheries decided to introduce a new food source for the salmon, a freshwater shrimp called the Mysis. Little did they know, the introduction of this shrimp would cause a dramatic disturbance to the ecosystem of Flathead Lake as an invasive species. Since the Mysis shrimp were much larger than the zooplankton, the fisheries thought that this new food source would help grow the kokanee salmon population. What they did not anticipate was that the Mysis shrimp stayed at the bottom of the lake during the day while the salmon were feeding, and swam up to the surface at night to eat the zooplankton. Furthermore, the lake trout began to feed on the shrimp while at the bottom of the lake and began to increase in size. Eventually the trout began to feed on the kokanee salmon as well.

You are in charge of a team leading a recovery strategy for Flathead Lake. By mapping out the flow of energy and matter between the web of organisms in and around the lake, you can develop a model to determine the results of the damage done by the introduction of the Mysis shrimp, and design a solution to restore some of the previous balance to this ecosystem.

UNDERSTAND ***Make sense of the information presented and understand the problem***
After reading the problem statement, go back and **mark up the text**. Identify the problem and highlight it. Place a checkmark (✓) next to anything that you have already learned. Underline information that is important to the problem statement. (Circle) words or ideas that you are unsure of their meaning, or would like to learn more about. **Go back to your notes and re-familiarize yourself with any words or ideas that you circled. Write down definitions or ideas that you'd like to remember here:**   **What is the problem? Identify and state it here:**   **What are you being asked to do to solve it? State it here:**

CONNECT ***Connect given information with prior knowledge and content understanding***

What information do I know? (connect information from the problem statement and your own knowledge to the problem presented)	**What information do I need to know or figure out?** (what am I wondering? What do I need to ask or discover to help solve this problem?)

Create a food web to map out the flow of energy and matter in and around Flathead Lake. Label the levels of producers and consumers appropriately and indicate the direction of energy flow through the ecosystem:

Explain the effect that the introduction of the Mysis shrimp has had on each of the other members of this ecosystem:

Do you have all the information you need to design a solution to this problem?

YES ▫ (move on to the next step)
MAYBE ▫ (review the information again, add anything that's missing - indicate what you added below)
NO ▫ (what do you think you are still missing? Try to find this info before moving on or ask for support)

IDEATE ***Map out your ideas for solving the problem***
Write or draw your ideas for solving this problem: (try sketches, mind maps, charts, etc…)

SYNTHESIZE ***Form your solution***
Restate the problem given and what you are trying to solve:
Explain a possible solution to this problem:

Claim (What you think is the most effective or reasonable solution)	**Evidence** (What information did you base your claim on?)	**Reasoning** (Explain why your solution is effective. Use your evidence to help support this)

Does your solution reasonably address the problem?

YES ▢ (great!)
MAYBE ▢ (explain where you may be able to go back and make changes or where you went back and made changes)
NO ▢ (explain why it may not, and ask for support)

REFLECT
Evaluate your process and conclusion

Describe one challenge you had in solving this problem and explain how you worked through it:

Did you come up with multiple possible solutions to this problem?

YES ▢
NO ▢

If YES, describe why you determined that your chosen solution was the most effective:

Look back on your work and explain something you could have done to solve this problem differently:

APPENDIX H

PROBLEM SOLVING TASK 4

MS-LS2-4: Ecosystems: Interactions, Energy and Dynamics

SEP	DCI	CC
Engaging in argument from evidence	Ecosystem characteristics can vary over time, as physical or biological disruptions can lead to shifts in populations.	Stability and change

PERFORMANCE EXPECTATION
Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations.

Observable features of student performance:

1. **Supported claims**
    a. Students make a claim to be supported about a given explanation or model for a phenomenon. In their claim, students include the idea that changes to physical or biological components of an ecosystem can affect the populations living there.
2. **Identifying scientific evidence**
    a. Students identify and describe the given evidence (e.g., evidence from data, scientific literature) needed for supporting the claim, including evidence about:
        i. Changes in the physical or biological components of an ecosystem, including the magnitude of the changes (e.g., data about rainfall, fires, predator removal, species introduction).
        ii. Changes in the populations of an ecosystem, including the magnitude of the changes (e.g., changes in population size, types of species present, and relative prevalence of a species within the ecosystem).
        iii. Evidence of causal and correlational relationships between changes in the components of an ecosystem with the changes in populations.
    b. Students use multiple valid and reliable sources of evidence.
3. **Evaluating and critiquing the evidence**
    a. Students evaluate the given evidence, identifying the necessary and sufficient evidence for supporting the claim.
    b. Students identify alternative interpretations of the evidence and describe why the evidence supports the student's claim.
4. **Reasoning and synthesis**
    a. Students use reasoning to connect the appropriate evidence to the claim and construct an oral or written argument about the causal relationship between physical and biological components of an ecosystem and changes in organism populations, based on patterns in the evidence. In the argument, students describe a chain of reasoning that includes:
        i. Specific changes in the physical or biological components of an ecosystem cause changes that can affect the survival and reproductive likelihood of organisms within that ecosystem (e.g., scarcity of food or the elimination of a predator will alter the survival and reproductive probability of some organisms).
        ii. Factors that affect the survival and reproduction of organisms can cause changes in the populations of those organisms.
        iii. Patterns in the evidence suggest that many different types of changes (e.g., changes in multiple types of physical and biological components) are correlated with changes in organism populations.

iv. Several consistent correlational patterns, along with the understanding of specific causal relationships between changes in the components of an ecosystem and changes in the survival and reproduction of organisms, suggest that many changes in physical or biological components of ecosystems can cause changes in populations of organisms.

v. Some small changes in physical or biological components of an ecosystem are associated with large changes in a population, suggesting that small changes in one component of an ecosystem can cause large changes in another component.

Prior knowledge connection:

- **Ecosystem:** the living and nonliving factors that work together and interact in an area
    - **Biotic factors:** living and once-living parts
    - **Abiotic factors:** nonliving parts (air, water, soil, sunlight, temperature, climate)
- **Feeding relationships:**
    - **Producers:** (a.k.a. autotrophs) make their own food (produce their own energy)
    - **Consumers:** (a.k.a. heterotrophs) consume other organisms for energy
        - **Herbivores:** plant eaters (eat producers)
        - **Carnivores:** meat eaters (eat other consumers)
            - **Scavengers:** eat the remains of organisms left behind by other animals
        - **Omnivores:** plant and animal eaters
        - **Decomposers:** omnivores that eat dead organisms and other waste
        - **Chemotrophs:** get energy directly from chemicals without using the sun
- **Food chain:** shows where different organisms get their food
    - **Primary consumer:** producer
    - **Secondary consumer:** eats the primary consumer for energy
    - **Tertiary consumer:** eats the secondary consumer for energy
- **Food webs:** show all of the feeding relationships and overlapping food chains
- **Energy and matter cycles**
    - **Energy cycle:** energy is passed through ecosystems through food chains and food webs
        - Only about 10% of the energy from one level gets passed on to the next
        - An energy pyramid shows the energy at each feeding level of an ecosystem
- **Limiting factors:** a resource or condition that limits the size of a population
- **Interdependence:** the reliance on other populations for survival within a community
    - **Competition:** organisms competing for the same resources
        - Well adapted members of a community are more likely to survive and reproduce
    - **Predation:** populations change because of predator/prey relationships
        - **Predators:** animals that eat other animals
        - **Prey:** the animals being eaten (amount of prey is a limiting factor)
    - **Cooperation:** when members of a population cooperate to help each other survive

Key vocabulary:

Ecosystem	Biotic factor	Abiotic factor	Producer
Consumer	Herbivore	Carnivore	Omnivore
Food chain	Primary consumer	Secondary consumer	Tertiary consumer
Food web	Energy cycle	Competition	Limiting factor

PST #4 MS-LS2-4

Problem statement:

Imagine you are an ecologist studying a forest ecosystem. In this forest, several species of birds, including the blue-winged warbler and the red-tailed hawk, interact within a delicate balance. Blue-winged warblers rely on caterpillars as their primary food source, while red-tailed hawks prey on both blue-winged warblers and other small mammals. The caterpillars, in turn, depend on the forest vegetation for shelter and nourishment.

In recent years, the forest ecosystem has undergone several changes in its physical and biological components. These changes have had an impact on the climate, the vegetation, and have created some competition for existing species. Your observations over this time period have resulted in the following data:

Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Blue-winged Warbler	100	95	80	65	60	45	40	30	15	10
Red-tailed Hawk	50	55	65	70	72	80	85	87	90	99
Caterpillar	2000	1800	1750	1500	1200	1000	700	600	300	200

Rainfall (in/year)	500	450	150	120	130	50	30	20	350	400
Parasitic fungus	0	0	100	400	500	750	900	1200	1500	1800
Invasive bird species	0	5	20	35	50	65	70	85	100	120

Your task is to evaluate and interpret the given information, and construct a well-supported argument using evidence to explain how changes to the physical or biological components of this ecosystem have affected the populations of the Blue-winged Warblers and the Red-tailed Hawks. (keep in mind that there could be other factors at play beyond what is expressed in this data)

UNDERSTAND
Make sense of the information presented and understand the problem

After reading the problem statement, go back and **mark up the text**. Identify the problem and highlight it. Place a checkmark (✓) next to anything that you have already learned. Underline information that is important to the problem statement. (Circle) words or ideas that you are unsure of their meaning, or would like to learn more about.

Go back to your notes and re-familiarize yourself with any words or ideas that you circled. Write down definitions or ideas that you'd like to remember here:

What is the problem? Identify and state it here:

What are you being asked to do? State it here:

CONNECT ***Connect given information with prior knowledge and content understanding***	
What information do I know? (connect information from the problem statement and your own knowledge to the scenario presented)	**What information do I need to know or figure out?** (what am I wondering? What do I need to ask or discover to help analyze this problem?)

Use this space to explore the evidence regarding the relationships and events occurring in this ecosystem. You can make a graph, energy diagram, chart, etc… to organize and evaluate the information provided:

Do you have all the information you need to begin constructing your argument for this problem?

YES ☐ (move on to the next step)
MAYBE ☐ (review the information again, add anything that's missing - indicate what you added below)
NO ☐ (what do you think you are still missing? Try to find this info before moving on or ask for support)

IDEATE
Map out your ideas for solving the problem

Write or draw your ideas for constructing your argument:
(try sketches, mind maps, charts, etc…)

SYNTHESIZE
Form your solution

Restate the problem given and what you are trying to accomplish:

Claim:
State your claim describing how changes to components of this ecosystem have affected the populations living there

Evidence:
Provide the information that supports the claim you are making

Reasoning:
Use your evidence and the patterns you've identified to support your claim and explain how the physical and biological components of this ecosystem affected the populations you've explored.

Does your analysis reasonably address the problem?

YES ☐ (great!)
MAYBE ☐ (explain where you may be able to go back and make changes or where you went back and made changes)
NO ☐ (explain why it may not, and ask for support)

REFLECT
Evaluate your process and conclusion

Describe one challenge you had in analyzing this problem and explain how you worked through it:

Did you come up with multiple possible analyses to this problem?

YES ☐
NO ☐

If YES, describe why you determined that your analysis was most reasonable:

Look back on your work and explain something you could have done to approach this problem differently:

APPENDIX I

RUBRIC AND PST BY METACOGNITIVE DOMAIN

PLANNING MONITORING EVALUATING

Problem Solving Task Rubric

Exemplary 4	Competent 3	Developing 2	Limited 1
Component 1: Understand *Students make sense of information presented to them and understand the problem*			
Thoroughly identifies key information by marking up the problem statement	Identifies key information by marking up the problem statement	Identifies some key information by marking up the problem statement	Does not identify key information in the problem statement
*Explores knowledge gaps through thorough and accurate written explanation	*Explores knowledge gaps through written explanation	*Attempts to explore knowledge gaps with inaccurate explanation	*Does not explore knowledge gaps
Articulates the problem beyond what is explicitly given	Accurately identifies and states the problem	Identifies and/or states the problem inaccurately	Does not identify and/or state the problem
Demonstrates thorough understanding of task through written explanation	Accurately identifies the task through written explanation	Partially identifies the task and/or misinterprets the task through written explanation	Does not understand the task or provide written explanation
Component 2: Connect *Students make connections between their knowledge and the problem, explain the ideas and concepts they extracted*			
Incorporates information with personal insights relevant to the problem and/or task	Identifies sufficient information that is relevant to the problem and/or task	Identifies information, some of which is relevant to the problem and/or task	Does not connect problem to existing knowledge
Demonstrates advanced thinking through extended reasoning/questions regarding unknown information	Identifies important questions and unknown information that must be determined	Identifies insufficient and/or some irrelevant unknown information to determine	Does not identify the need to determine further information to address the problem/task
Establishes deep reasoning and explanation by connecting information and answering preliminary questions from the problem statement	Demonstrates logical reasoning and explanation by connecting information and answering preliminary questions	Provides some reasoning and/or explanation for connections and preliminary questions	Does not provide reasoning and/or explanation
*Effectively evaluates and enhances understanding if needed	*Evaluates and enhances understanding if needed	*Does not fully enhance understanding when needed	*Does not enhance understanding when needed
Component 3: Ideate *Students use relevant concepts to formulate ideas and develop possible solutions*			
Thoroughly represents and extends their ideation process through visual evidence	Demonstrates visual evidence of ideation	Some visual attempt at ideation	Does not visually represent any aspect of the ideation process
Demonstrates advanced reasoning, illustrating multiple possible approaches relevant to solving the problem	Illustrates logical reasoning and multiple possible approaches relevant to solving the problem	Indicates some reasoning and at least one possible approach to solving the problem	Does not provide evidence of reasoning or approaches to solving the problem
Develops advanced considerations for each possible solution	Includes some extended considerations for each possible solution	Attempts to include some further considerations for at least one possible solution	Does not include any further considerations for possible solutions
Component 4: Synthesize *Students apply facts, concepts and ideas to establish and support their solution and evaluate their outcome*			
Produces a well-founded solution to the problem	Produces a reasonable solution to the problem	Produces a solution to the problem; may not be viable	Does not arrive at a solution to the problem
Thoroughly identifies evidence that support their solution	Provides some evidence that support their solution	Includes some evidence that may or may not support their solution	Does not provide any evidence that support their solution
Develops advanced reasoning rationalizing how the evidence supports their solution	Reasonably connects the evidence to their solution	Attempts to connect the evidence to their solution; does not support their claim	Does not connect the evidence to their solution
Accurately evaluates whether or not their final solution solves the problem	Indicates with some accuracy whether or not their final solution solves the problem	Struggles to recognize the accuracy or validity of their solution	Does not know what an accurate solution to the problem or question looks like
*Demonstrates a thorough analysis of possible errors	*Offers an accurate explanation for possible errors	*Attempts to indicate where an error may have occurred	*Does not attempt to provide an explanation
Component 5: Reflect *Students justify their conclusions and reflect on methods and challenges*			
*Identifies challenges and clearly articulates how they were handled	*Identifies challenges and reasonably explains how they were handled	*Attempts to identify challenges, does not articulate how they were handled	*Does not recognize that challenges were apparent; none identified
*Thoroughly explains how they chose their solution and rationale behind their process	*Offers a reasonable explanation of their process and choice of solution	*Attempts to explain their reasoning, but may be incomplete or lacking clarity	*Does not provide insight on their thought process
Examines their procedure and elaborates on alternative steps or outcomes	Explains where alternative steps or outcomes may exist	Indicates some alternative option, but does not explain it	Does not provide reflection on alternative steps or outcomes

PST #3 MS-LS2-3

Problem statement:

Flathead Lake is a freshwater lake in Northwestern Montana. This lake is home to a variety of phytoplankton and other underwater plants that use abiotic factors to create energy to support the animal life in and around the lake. As settlers began to build towns around Flathead Lake in the early 1900's, they started stocking the lake with non-native fish in order to increase fishing. Among the several types of fish that were introduced were the lake trout in 1905, and the kokanee salmon in 1916. The kokanee salmon live at the surface of the lake, where they feed on their main food source, the zooplankton. The zooplankton feed on the phytoplankton. As the kokanee salmon population grew over the years, bears and bald eagles came to the area and thrived as consumers by feeding on the salmon population.

In order to try and grow their population further, fisheries decided to introduce a new food source for the salmon, a freshwater shrimp called the Mysis. Little did they know, the introduction of this shrimp would cause a dramatic disturbance to the ecosystem of Flathead Lake as an invasive species. Since the Mysis shrimp were much larger than the zooplankton, the fisheries thought that this new food source would help grow the kokanee salmon population. What they did not anticipate was that the Mysis shrimp stayed at the bottom of the lake during the day while the salmon were feeding, and swam up to the surface at night to eat the zooplankton. Furthermore, the lake trout began to feed on the shrimp while at the bottom of the lake and began to increase in size. Eventually the trout began to feed on the kokanee salmon as well.

You are in charge of a team leading a recovery strategy for Flathead Lake. By mapping out the flow of energy and matter between the web of organisms in and around the lake, you can develop a model to determine the results of the damage done by the introduction of the Mysis shrimp, and design a solution to restore some of the previous balance to this ecosystem.

UNDERSTAND
Make sense of the information presented and understand the problem

After reading the problem statement, go back and **mark up the text**. Identify the problem and highlight it. Place a checkmark (✓) next to anything that you have already learned. Underline information that is important to the problem statement. (Circle) words or ideas that you are unsure of their meaning, or would like to learn more about.

Go back to your notes and re-familiarize yourself with any words or ideas that you circled. Write down definitions or ideas that you'd like to remember here:

What is the problem? Identify and state it here:

What are you being asked to do to solve it? State it here:

CONNECT
Connect given information with prior knowledge and content understanding

What information do I know? (connect information from the problem statement and your own knowledge to the problem presented)	**What information do I need to know or figure out?** (what am I wondering? What do I need to ask or discover to help solve this problem?)

Create a food web to map out the flow of energy and matter in and around Flathead Lake. Label the levels of producers and consumers appropriately and indicate the direction of energy flow through the ecosystem:

Explain the effect that the introduction of the Mysis shrimp has had on each of the other members of this ecosystem:

Do you have all the information you need to design a solution to this problem?

YES ☐ (move on to the next step)
MAYBE ☐ (review the information again, add anything that's missing - indicate what you added below)
NO ☐ (what do you think you are still missing? Try to find this info before moving on or ask for support)

IDEATE
Map out your ideas for solving the problem

Write or draw your ideas for solving this problem:
(try sketches, mind maps, charts, etc…)

SYNTHESIZE
Form your solution

Restate the problem given and what you are trying to solve:

Explain a possible solution to this problem:

Claim (What you think is the most effective or reasonable solution)	**Evidence** (What information did you base your claim on?)	**Reasoning** (Explain why your solution is effective. Use your evidence to help support this)

Does your solution reasonably address the problem?

YES ☐ (great!)
MAYBE ☐ (explain where you may be able to go back and make changes or where you went back and made changes)
NO ☐ (explain why it may not, and ask for support)

REFLECT
Evaluate your process and conclusion

Describe one challenge you had in solving this problem and explain how you worked through it:

Did you come up with multiple possible solutions to this problem?

YES ☐
NO ☐

If YES, describe why you determined that your chosen solution was the most effective:

Look back on your work and explain something you could have done to solve this problem differently: