ABSTRACT


The purpose of this study was to explore four elementary preservice teachers’ (PSTs) learning outcomes based on affective characteristics, science knowledge, and pedagogical content knowledge during a science methods course that incorporated explicit instruction on drawing-to-reason about force-related phenomena. Drawing-to-reason was defined as the creation, evaluation, and revision of hand-sketched visual representations to build science knowledge and considered a form of science modeling. The explicit instruction on drawing-to-reason was guided by Quillin and Thomas’s (2015) instructional intervention framework that targets affect, visual literacy, and modeling. This study used a mixed methods case study design with embedded subunits. Quantitative and qualitative data were collected during the semester and analyzed concurrently to explore the PSTs’ learning outcomes, including a) affective characteristics towards drawing, physical science and science teaching, b) science knowledge about force and motion concepts and the practice of drawing-to-reason, and c) pedagogical content knowledge about drawing as an instructional strategy for science teaching in the elementary grades. The PSTs, who were part of the case study, were undergraduate students in their 1st year of a STEM-focused elementary education program and had various prior knowledge about force and motion, drawing attitudes and experience, and science teaching efficacy beliefs (STEB). For learning outcomes based on affective characteristics, the primary data included a semantic differential attitude (SDA) survey (Bauer, 2008), T-STEM instrument (Unfried et al, 2022) to measure STEB, and semi-structured interviews. Primary data for science knowledge learning outcomes included a series of PST-generated drawings and written
explanation of a force-related phenomenon. Primary data for *pedagogical content knowledge* learning outcomes included lesson plans generated by the PSTs prior to and following explicit instruction on drawing-to-reason and end-of-course, semi-structured interview responses about lesson facilitation during field experiences. At the end of the course, PSTs’ self-reported *affective characteristics* were more positive toward drawing and science teaching. However, they appeared to perceive physical science as more difficult at the end of the semester. PSTs also built *science knowledge* about force and motion-related concepts and *drawing-to-reason* as a science practice. During the iterative drawing cycles, PSTs included more force and motion-related concepts to explain the phenomena and demonstrated changes in their drawing practices based on model use aspects defined as model relationships, purpose and salient features, and metacognition (Quillin & Thomas, 2015). Their final drawings included a greater variety of representational translations, including visual-text, vertical between scales, and horizontal within scale. The purpose of the PST-generated drawings progressed from primarily depicting observable features to including more salient features, such as non-observable structures, processes, and relationships, which reflected their understanding of the force-related phenomenon. Their final drawings served as the basis for their written explanation. While data to assess learning outcomes regarding *pedagogical content knowledge* of science instructional strategies was limited, PSTs did incorporate drawing in their lesson planning and facilitation in more ways that would support elementary students’ more expert modeling use of drawing as a tool for reasoning (Quillin & Thomas, 2015). This study has implications for building PSTs’ *affective characteristics, science knowledge*, and *pedagogical content knowledge* during teacher education programs to support future implementation of drawing as a science instructional strategy in the elementary classroom.

by
Teresa Lynette Leavens

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DEDICATION

“If you don’t like the road you’re walking, start paving a new one” ~Dolly Parton

To those in my life, both past and present, who have inspired, encouraged, and supported me in my education journey. There would be no new road without my supportive friends (RD, JH, KL, CE, HB…), my partner in life, and my children. Joy and gratitude.
BIOGRAPHY

Dr. Teresa Lynette Leavens is a native North Carolinian, who was born and raised in Burlington, North Carolina, a former textile town. She is a first-generation college graduate, who graduated magna cum laude with a B.S. in chemical engineering with a bioscience option from NC State University in 1990, and a PhD in toxicology from UNC-Chapel Hill in 1996. Her STEM career path was shaped by her parents’ emphasis on the value of education and by numerous individuals during her primary and secondary education, including her friend’s father, William West, who was biological photographer, numerous teachers such as her high school chemistry and physics instructor, Hobart Cook, and high school biology instructor, Dr. Donna Oliver, and school administrators such as high school principal, John Freeman, who modeled striving for excellence and persevering in the face of challenges, and counselor, Barry Aycock, who directed her towards the path of chemical engineering, a field with which she was not familiar, because of her interest in mathematics, physics and chemistry.

During her undergraduate studies in chemical engineering at NC State University, she participated in the Co-operative Education program and worked for IBM in Lexington, Kentucky, which sparked her initial interest in a research career. She worked with Dr. Loy Britto in the Materials Engineering Department during one semester to optimize components for the fuser rolls in IBM’s laser printer, including factors such as material properties for roller components that best used toner to paper fibers in various environmental conditions and the best paper weight and materials to use for printing. Her work was recognized along with Dr. Britto in an internal technical report.

Her interest in environmental health stemmed from her summer manager internship as an undergraduate at Proctor and Gamble Cellulose’s Pulp and Paper Mill in Perry, Florida. She was
responsible for monitoring and managing water quality in the plant, both for manufacturing purposes, as well as potable water for human use and consumption. This sparked her interest in what makes certain water contaminants, such as nitrates and sulfates, harmful to people, and how the safe consumption levels are determined. Therefore, after receiving her B.S. in chemical engineering, she pursued a doctoral degree in toxicology at UNC-Chapel Hill in their Curriculum in Toxicology.

The focus of Dr. Leavens’ doctoral research in toxicology was physiologically based pharmacokinetic modeling. She worked under the direction of Drs. Roger McClellan and James Bond on her research and dissertation entitled “Metabolic Interactions and Genotoxicity of 1,3-Butadiene and Styrene in Male B6C3F1 Mice”. Although her background in chemical engineering was unique in the field of toxicology at the time, it was well suited to her research interests. In the early 1990s, physiologically based pharmacokinetic modeling was gaining interest and acceptance in the field of human health risk assessment, and she had the opportunity to interact with many of the early researchers of physiological models in the field. Her engineering background was useful both for modeling, as well as the experimental aspects of her project such as designing and constructing an inhalation exposure system for the research.

Her career as a scientist focused on the pharmacokinetics of environmental contaminants and drugs with a primary focus on kinetic modeling, particularly physiologically based pharmacokinetic modeling. During her professional career, she worked as a researcher for the US Environmental Protection Agency, the Hamner Institutes of Health Sciences, NC State University School of Veterinary Medicine, and as an Independent Pharmacokinetic Consultant. She was involved with and published articles (~ 70 peer-reviewed articles, presentation abstracts, book chapters, and reports) on both experimental and computational research in animals and
humans for a wide range of compounds, including persistent environmental compounds, water contaminants, air contaminants, metals, nanoparticles, and veterinary drugs used in food-production animals. In addition to instructing courses on pharmacokinetics and modeling, she provided technical expertise as a reviewer for the ATSDR Toxicological Profile for Styrene, as a member of an ILSI working group on establishing physiological parameters for early life stages, as a consultant reviewing EPA’s PBPK model for methanol to be used for establishing reference doses and concentrations, and as an ad hoc member of the U.S. EPA FIFRA Scientific Advisory Panel.

Dr. Leavens served in numerous professional service and leadership positions in engineering and toxicology. In undergraduate school she was active in the student chapter of the American Institute of Chemical Engineers from 1986 to 1990 and was the president of the NC State University chapter in 1990. She was active in both the national and local chapters the Society of Toxicology serving in the national chapter as a Councilor in the Risk Assessment Specialty Section from, a member of the Education committee from 2011 to 2012, the Education Committee Co-Chair from 2012 to 2013, and the Education Committee Chair from 2013 to 2014. In the local chapter she acted as newsletter editor from 2010 to 2012. During her time on the Education Committee, she worked to support increasing diversity in the field of toxicology through the Tox Scholar program, which expands awareness about the field of toxicology to undergraduates in universities with high percentages of students, who have been historically underrepresented in STEM.

While long a skeptic of the meaning or purpose of awards, Dr. Leavens has had the honor of being the recipient of several awards and recognitions during her educational and professional career. During her undergraduate studies she was recognize for academic excellence in
engineering with the St Patrick award and received an American Fibers Industry Scholarship her senior year. During her doctoral studies in toxicology, she was the recipient of a graduate student graduate student award for best presentation in pharmacokinetics at the 6th Annual ISSX Meeting, a student travel award from the Society of Toxicology for their annual meeting, and the Inhalation Specialty Section Student Award for her research. She was also the recipient of an EPA Scientific and Technology Achievement award for her pharmacokinetic research with water disinfection byproducts. During her doctoral studies in the College of Education, she was inducted in the Kappa Delta Pi for academic achievement and was selected and completed the Preparing the Professoriate program from 2020 to 2021.

Throughout her career, Dr. Leavens has been involved in outreach work at various levels of education to support science engagement and interest of individuals, particularly those who have been traditionally marginalized in STEM careers. Over her career, she has volunteered in local elementary and middle schools in Wake and Johnston County for STEM career days to bring awareness to the field of toxicology, specifically, and to STEM careers, in general. During her doctoral work in toxicology, Dr. Leavens volunteered with the Big Brother program in Wake County, organized science activities at the Chemical Industry Institute of Toxicology for “Take Your Daughter to Work Day,” and participated in science demonstrations for middle school classes and teacher workshops. During her postdoctoral trainee position at the US EPA Human Studies Division, she volunteered as a mentor in the UNC School of Medicine’s “Health Professions Partnership Initiative,” which had the goal of increasing diversity in the health care profession by providing summer research experiences for underrepresented minority high school students. From 2007 to 2017 Dr. Leavens was involved with a volunteer tutoring and academic enrichment program at Briarcliff Elementary School in Cary, NC. She served as the lead for the
program to coordinate the team of volunteers to plan and prepare materials for the enrichment activities in reading, mathematics, and science for grades K-5, in addition to serving as a group facilitator with students. During the 2016 to 2017 academic year, Dr. Leavens worked as a mathematics teaching assistant at Briarcliff elementary supporting students in grades K-5.

During her doctoral studies in the elementary education in mathematics and science program, Dr. Leavens has had a variety of opportunities that have broadened her knowledge and experiences in education. In the fall of 2017, she assisted Dr. Sarah Carrier with physical science activities for elementary age students as part of the College of Education STEM Fair. She was also invited by Dr. Margareta Thomson in 2018 and 2019 to present information about the STEM education pipeline and engage with secondary teachers participating in a summer professional development program with the Center for Human Health and the Environment in the College of Science at NC State University. In the summer of 2018, she also traveled to Finland and Estonia in a Study Abroad Program with a cohort of students from the College of Education to gain an international perspective on elementary education and teacher education programs. Dr. Leavens was the recipient of a travel award for a study abroad trip to Mexico for the summer of 2019, which was unfortunately cancelled due to safety concerns. Part of her Research Assistant responsibilities during her work with Dr. Paola Sztajn from 2019 and 2021 was assisting with planning and facilitation of the NC State University Math Summit for local elementary and secondary teachers. In particular, she gained invaluable experience with organizing virtual conferences when plans had to be adapted for the 2020 Summit due to COVID-19. One of the highlights of her outreach during her doctoral studies was working with local Latino/Latina families to support STEM educational opportunities. In 2019, she organized and led a week-long science summer camp entitled “Intertwined” for a local group of families in
the Fiesta Cristiana community. In 2020, she received a mini-grant from Environmental Educators of North Carolina to support organizing and expanding the science camp to more elementary and middle school students, but unfortunately the camp had to be canceled due to COVID-19. She also worked with leaders from Semillas de Unidad, to organize a mathematics training session for tutor volunteers with Drs. Valerie Faulkner and Temple Walkowiak.

Dr. Leavens is now looking forward to where her journey in education takes her next.
ACKNOWLEDGMENTS

First, I want to thank my committee members, Drs. Sarah Carrier, Jill Griffenhagen, Gail Jones, and Eric Wiebe, and my chair James Minogue, for their time, guidance, and patience with my dissertation research. Their probing questions, insight, and advice during my oral examinations and feedback on my written work was instrumental for planning, analyzing, and reporting my research. I also want to recognize Irene Armstrong for all her administrative help with the doctoral degree requirements.

I also am grateful to the Elementary Education Program for the opportunity to work with preservice teachers in both the Engineering and Intermediate Grades Science Methods courses. The teaching experience and my agency as the instructor were invaluable and will be one of my most treasured experiences from my doctoral studies. I was able to work with and learn from amazing students whose knowledge, skills and compassion will enrich the lives of children as they move forward in their chosen career path. I am thankful to the participants in my research who generously volunteered their time and shared their coursework to assist me. My dissertation would not have been possible without them.

In addition, I am grateful to Laura Fogle, director of METRC, and Kerri Brown Parker, the former director of METRC. They were invaluable assets for me at the College of Education. I benefited both in my teaching and my research from their support and knowledge during my doctoral work.

And finally, I am grateful to Drs. Rebekah Davis and Jennifer Houchins for their support and encouragement as colleagues and friends during my doctoral work. I appreciate their feedback and ideas on my proposal, data analysis, and dissertation. COVID-19 complicated the pursuit of my degree in many ways, both personally and professionally, and they, along with my
family and close friends, helped me maintain perspective that “what is essential is invisible to the 
eye” (Antoine de Saint-Exupery in *Le Petit Prince*).
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<tr>
<td>PCK</td>
<td>Pedagogical content knowledge</td>
</tr>
<tr>
<td>PST</td>
<td>Preservice Teachers</td>
</tr>
<tr>
<td>QUAL</td>
<td>Qualitative analysis</td>
</tr>
<tr>
<td>QUAN</td>
<td>Quantitative analysis</td>
</tr>
<tr>
<td>SK</td>
<td>Science knowledge</td>
</tr>
<tr>
<td>SDA</td>
<td>Semantic differential attitudes</td>
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<td>STEB</td>
<td>Science teaching efficacy belief</td>
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CHAPTER 1

INTRODUCTION

This chapter provides an overview of drawing in science, motivation for the study, research purpose statement, and research questions for the study.

Overview

Meaning making in science is multi-modal; visual representation along with mathematical expressions and written or spoken text are all valuable to fully convey an explanation for scientific phenomena. World-renowned scientist, Albert Einstein famously said, “The greatest scientists are artists as well” (Einstein Archive 22-257). To put it another way, “To do science, to talk science, to read and write science, it is necessary to juggle and combine in various canonical ways verbal discourse, mathematical expression, graphical-visual representation, and the motor operations in the world” (Lemke, 1998, p.87). For example, consider the concept of force in the scenario of a ball falling from a location elevated above the floor. Newton’s laws that describe the phenomena can be written as mathematical equations, but the written equations are best understood with a labeled visual diagram or illustration of what is being modeled, and a written description to bound the variables in the equations (i.e., height from which the ball is falling, the ball’s mass, location of event to determine gravitational force). Swiss educator Johann Heinrich Pestalozzi (1746 – 1827) developed a concept called Anschauung, which refers to a mental image that is developed from experiences. Pestalozzi’s idea was that sense-making involves form, numeracy, and text to construct knowledge along a multistage path that proceeds from confusion to clarity (van der Veen, 2012). While all three representational forms provide important and complementary information, the role of generating visual representations in understanding and communicating science ideas has not been mirrored
in the instructional practices of the classroom, where reading and writing historically have been the privileged modes for building knowledge. To provide all children with the best chance to build their science understandings, “Our curriculum should be designed to help children acquire multiple forms of literacy” (Eisner, 2005; p. 109).

Making marks in the form of images comes naturally for young children (Gardner, 1980), and they typically enter their formal education with the ability to use drawings to express their understanding of the world around them. However, the classroom learning environment in the US public elementary schools has tended to marginalize the educational role of drawings as art in general (Efland, 2002), as well as the value of drawing-to-reason and communicate, in particular (Short & Kaufman, 2000). Between the ages of 9 to 11, most children will no longer produce spontaneous drawings to represent ideas and have become self-conscious about their perceived ability to draw (Gardner, 1980). Recent science education research supports drawing as an important instructional strategy for children’s engagement, communication, reasoning, and learning in science (Ainsworth et al., 2011; Edens & Potter, 2003; Ehrlén, 2009; Osborne & Cosgrove, 1983; Prain & Tytler, 2012; Williams et al., 2019; Zhang & Lin, 2011). National science research and educational agencies have stressed the importance of engaging children in authentic science practices, such as construction of models, which includes drawings generated by students to reason and communicate their thinking (NRC, 2012). Therefore, students will need explicit instruction and scaffolded practice to support their use of drawing as an epistemic tool in the classroom.

Teachers are key factors in students’ achievement (Darling-Hammond, 2000), and their sense of preparation for science teaching has been shown to influence their instructional practices regarding the extent and type of science lessons incorporated in the classroom.
(Appleton, 2003). The 2018 National Survey on Science and Mathematics Education (NSSME) indicated most elementary teachers did not feel well prepared to teach science in general, and physical science, in particular (Trygstad, 2020). Teachers’ beliefs concerning their efficacy in the classroom have been found to “affect their general orientation toward the educational process as well as their specific instructional activities” (Bandura, 1997, p. 241). The teacher-reported lack of preparation in the NSSME (Trygstad, 2020) also was reflected in the type of activities reported in the classroom, where only 15% of novice teachers (teachers with less than five years’ experience) felt very well prepared to help “develop students’ abilities to do science” (p. 39), including developing scientific models. Teachers’ knowledge of and affective characteristics (e.g. attitudes, interest, self-efficacy, and value) towards drawing will be important for more wide-spread incorporation and effective implementation in the elementary science classroom (Areljung et al., 2021).

Preservice teachers’ (PSTs) own education experiences influence their desire, confidence, and abilities to teach science (Appleton, 2003; Avraamidou, 2013). However, professional development, which begins in the teacher education programs, also can play a key role in influencing their affective characteristics towards science and science teaching and building both science knowledge (SK) and pedagogical content knowledge (PCK) of instructional strategies (Avraamidou, 2013; Buczynski & Hansen, 2010; Garet et al., 2001; Heller et al., 2012; Kennedy, 1999; Scher & O’Reilly, 2009; Singh, 2022; Supovitz & Turner, 2000). Therefore, the purpose of this research is to explore how incorporation of explicit instruction on drawing-to-reason about force-related phenomena may be beneficial to elementary PSTs during their teacher education, including supporting more positive affective characteristics, deepening SK about
force & motion, and building PCK about drawing as an instructional strategy in elementary science education.

**Drawing**

The concept of drawing has an array of definitions depending on the focus of the research study or the contextual application for drawing, which includes the fields of visual literacy, visual thinking, graphicacy, and modeling. McKim (1972), whose book *Experiences in Visual Thinking* is considered foundational in the field of design (Myers, 2022), explored drawing as an essential component of visual thinking in which seeing, drawing, and imagining are part of an interactive process. During ideation in visual thinking, an individual iteratively expresses and evaluates their drawings while exploring internal mental ideas. It is this concept of drawing as a process versus a product that is important for learning.

Science drawings are static, two-dimensional, visual representations generated by mark-making on medium to depict “any type of [science] content…[including] structure, relationship, or process” (Quillin & Thomas, 2015, p. 2). They may contain written text such as labels or legends to clarify pictorial information. Drawings as *products* are generated primarily to communicate a final, refined idea. Drawing as a *process* is defined as mark-making based on an individual’s ideas (i.e., not generated by comparison with canonical models and representations), so that drawings are “tools to think with” (Kindfield, 1994, p. 1). In this research the term *drawing-to-reason* is used to indicate the process of drawing in which an individual creates, evaluates, and revises hand-sketched drawings to create external, visual representations of their evolving ideas about science phenomena.

**Drawing as an Expert Science Practice**

Drawing has been an important practice of scientists and engineers for problem-solving
and communicating ideas throughout history (McKim, 1972). Notable examples include da Vinci, Einstein, Tesla, and Edison. Leonardo da Vinci impacted our knowledge of nature and natural phenomena through his artistic ability to illustrate observations and knowledge of a broad range of scientific and engineering disciplines (Shoja et al., 2013). Edison sketched his evolving ideas for the lightbulb in his personal notebooks (Hanks & Belliston, 1977; McKim, 1972). Einstein discussed how his imagination was driven by visualization and noted that “words or the language, as they are written and spoken, do not seem to play any role in my mechanism of thought” (McKim, 1972, p. 9). Physics experts often automatically draw diagrams for problem-solving (Dufresne et al., 1997; Ibrahim & Rebello, 2012; Reif, 1995). A key component of undergraduate engineering education historically has been technical drawing, both for the purpose of generating ideas, as well as understanding and interpreting others’ drawings (ASEE, 1955). And while computer-aided design (CAD) has dominated the production of final technical drawings in the past 20 years, manual sketching and drawing with pencil and paper have been shown to be important in idea generation and problem-solving (Goldschmidt, 2014; Marklin et al., 2013; Schütze et al., 2003; Yang, 2009). Undergraduate science students are enculturated into the practice of drawing for observing, reasoning, and communicating during their courses and lab work (Maries & Singh, 2017).

Children’s Drawings

Children naturally draw during their development and exploration of the world (Baghban, 2007). Picasso once quoted that “Every child is an artist. The problem is how to remain an artist as he [she] grows up…” (Anning, 1997, p 225). Primary and secondary education in the U.S. has not promoted the process of drawing as a meaningful and intellectual tool for learning and communication in the classroom, but rather as an additional or fun activity that is primarily for
aesthetic purposes (Anning, 1997). In the U.S., as well as other Western countries, art, in general, has been viewed as entertainment and not as a serious intellectual pursuit (Efland, 2002). Students enter kindergarten viewing drawing as a way to express themselves, but by the age of nine to ten children become concerned with realism in their drawings (Winner, 1982), which can result in most children becoming self-conscious of their drawing abilities. This change in affect about drawing in a formal classroom setting, which values written or verbal text for communication and lacks direct instructional support for drawing, results in diminished use of drawing as a tool for thinking and communication (Adoniou, 2013; 2014).

**Drawing in Science Education**

Ainsworth et al. (2011) identified five distinct reasons for incorporation of drawing in the elementary grades to support science instruction, including (a) to enhance engagement, (b) to learn to represent science (Vosniadou et al., 2005), (c) to reason in science, (d) to use as a learning strategy (Van Meter, 2001), and (e) to communicate ideas to others (Özsoy, 2012; Reiss & Tunnicliffe, 2001; Rennie & Jarvis, 1995; Williams et al., 2019; Villarroel & Ros, 2013). While defined as distinct, the purposes are interrelated, and drawings are often incorporated into the lessons for multiple purposes. For example, to create interest in the content while drawing to reason about a phenomenon to build conceptual understanding. As an added benefit, “Students learn deeper knowledge when they engage in activities that are similar to the everyday activities of professionals who work in a discipline” (Sawyer, 2006, p. 4).

Recent frameworks and national standards have shifted the focus of science education to “what a student needs to do to learn science” (Duschl, 2008, p. 269) versus what they should know. The *Framework for K-12 Science Education* (NRC, 2012) and *Next Generation Science Standards* (NRC, 2013) emphasized the need for K-12 students to engage in science and
engineering practices as they build SK. One of the recommended practices for teachers to incorporate in the classroom is modeling. Scientific models are representations of phenomena and can serve as concrete instantiations of abstract or invisible concepts. They can take many forms including mathematical algorithms, computer simulations, graphs, and visual representations, which includes drawings. Students in all grade levels likely will need explicit instruction and scaffolding to gain the visual literacy skills needed to use drawing as a form of scientific modeling, but this is often not attended to by teachers (Lowe, 2000). This may be due to a lack of PCK for the use of drawing as an instructional strategy in the science classroom, which differs from everyday drawing and sketching. Prain and Waldrip (2006) discussed the need for teachers to be specifically trained to use and produce images because of the relative importance to children learning science. Teacher education programs provide a critical window of time to initiate PCK of instructional strategies for PSTs, particularly since elementary teachers often have limited opportunities to participate in science professional development (Banilower et al., 2013).

**Elementary Teachers**

“What teachers do matters” (Hattie, 2009, p. 22). Teachers need confidence in their SK and instructional practices to enact student-focused support for meaning-making in the classroom. Elementary teachers’ effective use of drawing as a strategy for science learning will depend on building their own CK and PCK to help them understand students’ ideas, recognize developing concepts, and implement drawing in a way that supports their students’ effective use as a science practice. Anderson (1996) categorized the challenges that teachers face in implementing reform-based science instruction, such as scientific practices like drawing, into three dimensions, including technical, political, and cultural. The technical dimension
encompasses issues that relate to the teacher’s own SK and PCK, as well as the training to achieve preparation for teaching science. Elementary teachers have reported both a lack of confidence in their SK and PCK regarding the physical sciences in particular (Banilower, 2019).

Science Knowledge (SK)

Studies have shown that teachers may hold similar alternate conceptions to students (Stepans, 1988) and have limited knowledge of certain science topics (Davis, Petish & Smithey, 2006). The extent of SK may limit an elementary teacher’s ability to monitor student understanding and may influence whether the teacher uses ineffective didactic practices that focus on memorization of facts and the perceived correct answer (Gomez-Zwiep, 2008) versus pedagogical practices that allow students to construct meaning during inquiry (Windschitl, 2002). Elementary teachers cannot effectively bridge the gap between students’ prior conceptions in science and more accurate internal mental models if they are limited in their own SK (Yip, 1998). Ball (2000) noted that teachers’ “understanding subject matter is essential to listening flexibly to others and hearing what they are saying or where they might be heading” (p. 242).

Pedagogical Content Knowledge (PCK)

However, inclusion of more science content-focused courses during undergraduate training has not been found effective for helping PSTs build the knowledge they need for effective classroom practices (Davis et. al., 2006; McDermott et al., 2006). Abell (2008), Johnston and Ahtee (2006), and McDermott et al. (2006) emphasized the need for PSTs to have both SK and PCK, because both types of knowledge are interconnected to support teachers’ classroom practices. One way for PSTs to gain both types is “learning by doing” (Sikandar, 2015, p. 215), which provides an opportunity to build both SK and PCK simultaneously.
(McDermott et al., 2006). Incorporation of drawing-to-reason in science during elementary PSTs’ method courses might have the same synergistic effect.

Consistent with Dewey’s theory of learning by doing (Sikandar, 2015), Stofflet and Staddard (1994) stated that “if teachers are to use conceptual teaching methods in their own classrooms, they need to learn content and pedagogy through the same conceptually based methods reformers are advocating be used with grade school students.” (p.32). Ball and Forzani (2009) advocate for teacher education programs to include "high leverage practices … that are essential for skillful beginning teachers to understand, take responsibility for, and be prepared to carry out in order to enact their core instructional responsibilities” (p. 504). Drawing-to-reason can be considered a high-leverage activity for PSTs because engaging in the process of drawing can simultaneously build both SK and PCK through accessible means to learning (Katz, 2017) in a subject domain (physical sciences) that is often cited as being hard and abstract for PSTs (Johnston & Ahtee, 2006). Clement (1989) pointed out that teachers tend to focus on empirical laws and quantitative formulas as being evidence of what they would define as science, but instead need to focus on “activities that are aimed at forming explanatory models” (p.377). Drawing-to-reason falls under the broad definition of modeling in science (Lehrer & Schauble, 2000). Schwarz (2009) and Nelson and Davis (2012) have explored how incorporation of modeling practices in preservice methods courses positively influences the PSTs’ PCK of modeling. Research on drawing with preservice elementary teachers appears to be limited predominately to assessing beliefs about science and science teaching (Minogue, 2010; Mensah, 2011). There is limited research on what educational value drawing-to-reason may have for preservice elementary teachers.
Drawing Instructional Interventions

Quillin and Thomas (2015) proposed an intervention framework for explicit instruction to support students becoming more expert in their use of drawings as a tool for science reasoning. The framework’s instructional interventions target students’ affective characteristics, visual literacy, and modeling (Figure 1.1). For their framework, they proposed sequential interventions with interactive feedback, so that science modeling instruction builds on, as well as influences visual literacy and affective interventions.

Figure 1.1

*Instructional Interventions for Drawing-to-Reason*

Note. Quillin and Thomas (2015) instructional intervention framework for drawing-to-reason

*Affective Interventions*

Educational research in a range of areas shows that learning is intertwined with affect (Weiss, 2000). What individuals like, view as valuable and interesting, and feel efficacious towards guide their actions. When it comes to drawing, children enter school ready to draw
(Gardner, 1980). During the elementary years, children become self-conscious of their perceived drawing ability and begin to refrain from using it as part of their learning and communication. There is also an academic tendency to view drawing as an artistic endeavor that is non-cognitive and related to innate giftedness. Students will be more likely to use drawings as a tool for reasoning in science if they are supported by affective interventions that target positive attitudes towards drawing, create interest in drawing, which elevate the value of drawing beyond an artistic pursuit, and nurture self-efficacy.

**Visual Literacy Interventions**

“Visual literacy involves the ability to understand, produce, and use culturally significant images” (Felten, 2008, p.60). Of all our senses, our vision is the most common mode through which we perceive the world around us.

While some have asserted that today’s generation of learners, who are immersed in visual images through our modern digital technologies, are visual experts (Prensky, 2001; Tapscott, 2009), their arguments are considered generalizations without strong research evidence (Brumberger, 2011). In a survey on undergraduates’ visual literacy regarding proficient use and ability to critically interpret visual information, Brumberger (2011) found that while students self-reported significant use of visual technologies, they self-reported limited proficiency with production of images and had difficulty critically evaluating photographs to discern alterations and extract relevant information. Felten (2008) notes, “Living in an image-rich world…does not mean students…naturally possess sophisticated visual literacy skills, just as continually listening to an iPod does not teach a person to critically analyze or create music” (p. 60).

While the increasing focus on visual literacy is driven in part by an interest or impetus to use and interact with digital technological tools for meaning making, the low-tech tool of
drawing with pen or pencil and paper has long been a vital way of meaning making for scientists and engineers. Perhaps the most notable example is Leonardo Da Vinci, who was equally known both for his artwork and his science drawings. His prolific drawings in his notebooks have provided insight into his thinking about the natural and human-made world.

McTigue and Flowers (2011) have emphasized the necessity of visual images to learn science. In the current digital world that is image rich, visual literacy is as important as verbal literacy as a 21st century skill. The concept of visual literacy evolved from an eclectic mix of theories and disciplines, including linguistics, art, psychology, and philosophy (Hortin, 1994). There have been many different definitions about what is meant by visual literacy based on researchers’ interests or backgrounds, but one relevant to this study is visual literacy as an individual’s ability to “use (write) images and to think and learn in terms of images” (Hortin, 1983, p.99). In this article on the increasing role that visual images play in our culture, Felten (2008) noted, “Just as writing is essential to textual literacy, the capacity to manipulate and make meaning with images is a core component of visual literacy” (p. 61). Visual literacy is multidisciplinary; the context in which images are created or used will matter for being able to communicate.

**Modeling Interventions**

One of the main goals of science is to understand how the natural and human-made world around us works. A primary tool that scientists use for reasoning are models, which can assist with understanding by idealization and abstraction of key information to simplify complex (Schwarz et al., 2009). Abstraction allows an individual to focus on important, influential details, and idealization focuses on conditions in which the phenomenon is most easily understood or explained. Models make aspects of the world easier to understand by pulling out features
necessary to explain and defining them simplistically to allow comprehension. In practice, scientists use models as they build their SK (Clement, 1989) and cycle through a process of construction, evaluation, and modification.

Although there is a philosophical debate about what a model is ontologically and its epistemological function for generating knowledge (Frigg and Nguyen, 2017), they can be broadly understood as representations that stand for something else. The something else can be a physical object, system, process, or a nonphysical entity like a mental or imagined idea or concept. For this research, modeling is defined as the process of iteratively creating, evaluating, and revising a model to infer a causal explanation for an observed process or system. In this research, drawings are conceptualized as external models of PSTs’ mental models and serve as “tools to think with” (Kindfield, 1994, p.1). The drawing process can be thought of as modeling to make inferences about the explanation for science phenomena (Harrison & Treagust, 2000).

Problem Statement

Scientific concepts are best explained through visual images combined with written and spoken text. Educational agencies and current national science standards emphasize the need for children to engage with science through authentic practices, and this includes drawing to make meaning of the world. There is currently limited use of drawings in elementary classrooms as an epistemic tool, where verbal and written text dominate classroom discourse, and drawing is often seen as a non-cognitive activity that is peripheral to serious educational endeavors. While drawing is an innate activity of young children, elementary students will need encouragement and direct instruction to be able to use drawing as a tool for reasoning about science phenomena. Therefore, elementary teachers, who have had limited experience with constructivist activities such as drawing during their own educational experiences, will need explicit guidance and
experiences with drawing-to-reason in science. They will need to build PCK about drawing as an instructional strategy in science, while at the same time deepening their own SK.

**Purpose Statement**

The purpose of this study was to explore four elementary PSTs’ learning outcomes based on affective characteristics, science knowledge, and pedagogical content knowledge during a science methods course that incorporated explicit instruction on drawing-to-reason about force-related phenomena. Drawing-to-reason was defined as the creation, evaluation, and revision of hand-sketched drawings to represent an individual’s own ideas about science phenomena and therefore, was considered a form of modeling. The explicit instruction on drawing-to-reason was guided by Quillin and Thomas’s (2015) instructional intervention framework that targets affect, visual literacy, and modeling.

This study used a mixed methods case study design with embedded subunits. Quantitative and qualitative data were collected during the semester and analyzed concurrently to explore the PSTs’ learning outcomes, including a) affective characteristics towards drawing, physical science and science teaching, b) science knowledge (SK) about force and motion concepts and the practice of drawing-to-reason, and c) pedagogical content knowledge (PCK) about drawing as an instructional strategy for science teaching in the elementary grades. For this study, the main unit of analysis was a class section of junior-year PSTs during their intermediate level (grades 3-5) science methods course that included explicit instruction on drawing-to-reason about intermolecular water forces.

The science methods course was a required component of the PSTs’ undergraduate STEM-focused elementary education program, while the explicit-instruction on drawing-to-reason was included as part of the science methods course content for the purpose of this study.
The embedded subunits for the overall case were four individual PSTs from the science methods course, who had various levels of prior force & motion SK and differing initial affective characteristics towards drawing, physical science, and teaching.

**Research Questions**

The central research question for this mixed methods study was: What are PSTs’ learning outcomes based on affective characteristics, SK, and PCK from an elementary science methods course that incorporates explicit instruction on drawing-to-reason? This central question is explored via the following sub-questions:

1. How do PSTs’ self-reported affective characteristics towards drawing, physical science, and science teaching change from the beginning to the end of the science methods course with explicit instruction on drawing-to-reason?

2. How do PSTs’ ideas and drawings about force-related phenomena evolve over a series of lessons that include explicit instruction on drawing-to-reason?

3. In what ways do PSTs incorporate drawing as an instructional strategy in their science lessons for field experiences after explicit instruction on drawing-to-reason?

Sub-question one quantitatively and qualitatively explored learning outcomes based on affective characteristics after explicit instruction on drawing-to-reason. Survey instruments, including a Semantic Differential Attitude Instrument (Bauer, 2008) and T-STEM instrument (Unfried et al., 2022), were used to measure constructs of PSTs’ affective characteristics, including attitude, interest, value, and self-efficacy, towards drawing in science, physical science and science teaching at the beginning and end of the semester (See Appendix B & C for T-STEM and SDA). In addition, PSTs were asked about their affective characteristics towards
both drawing in science and science teaching during semi-structured interviews at the end of the semester.

Sub-question Two quantitatively and qualitatively explored \textit{SK learning outcomes} about force-related phenomena and about science practice of drawing after \textit{explicit instruction} on \textit{drawing-to-reason}. General SK ideas about force & motion were measured with the multiple-choice assessment, ATLAST Force & Motion Teacher Assessment (Horizon Research, Inc, 2011a), at the beginning and end of the semester (See Appendix for information of the ATLAST assessment). PSTs’ SK about intermolecular water forces, which was the focus of the series of lessons on \textit{drawing-to-reason}, were assessed based ideas included in the PST-generated drawings about the lesson’s phenomena and their final written explanations. Their knowledge about drawing as a science practice was assessed based on aspects of model use in science, including \textit{model relationships, purpose and salient features, and metacognition} (Quillin & Thomas, 2015).

Sub-question three qualitatively explored \textit{PCK learning outcomes} about drawing as an instructional strategy for elementary science after \textit{explicit instruction} on \textit{drawing-to-reason}. PSTs’ science lesson plans and interview responses regarding lesson planning and facilitation during field experiences were used to explore how their instructional practices might support elementary students’ use of drawing as a science modeling practice. The lesson plans and interview responses were deductively coded based on aspects of model use by novices versus expert scientists, including \textit{model relationships, purpose and salient features, and metacognition} (Quillin & Thomas, 2015). During semi-structured interviews at the end of the semester, PSTs also shared self-assessment of their learning regarding drawing-to-reason as an instructional strategy and teaching elementary science, both in general and in specific content areas.
Definitions of terms as used in this study:

**Alternate or everyday knowledge:** An individual’s science ideas that are based on their experiences but are not in full alignment with canonical explanations for phenomena.

**Affect:** Krathwol, Bloom, and Masia (1973) recognized affect, along with cognition and psychomotor skills, as a target of learning and defined it as “the manner in which we deal with things emotionally, such as feeling, values, appreciation, enthusiasms, motivations, and attitudes” (Hoque, 2016).

**Affective characteristics:** Characteristics involving an individual’s typical feelings, which along with cognitive and psycho-motor processes, influence learning and actions. Based on Anderson and Bourke (2000), the feelings involved are stable (traits versus states) and have both directionality and level of intensity. Relevant affective characteristics for this research include attitude, interest, self-efficacy, and value.

**Attitude:** An affective characteristic defined as a "latent disposition or tendency to respond with some degree of favorableness or unfavorableness” (Fishbein & Ajzen, 2009, p. 76). It is conceptualized as having multiple components, including affect, and is considered to be a learned characteristic that involves typical feelings towards an idea, object, or activity (Anderson and Bourke, 2000).

**Canonical:** Science concepts, theories, and laws currently accepted as explanations of the natural world by the community of science experts.

**Concepts:** Science ideas that are building blocks for canonical explanations of science phenomena. In this research the concepts are ontologically categorized as
structures, processes, or relationships, and organized based on “big ideas” (Harlen, 2010, p.1), which is a term for broad ideas that can be applied to understand a variety of scientific phenomena.

**Drawing:** The process of mark-making on any medium to create an “external visual representation depicting any type of science content…[including] structure, relationship, or process” (Quillin & Thomas, 2015, p 2). In this research, the process of drawing involved the use of pencils and loose-leaf paper to create external representations that included both visual images and text to express ideas.

**Drawing-to-reason:** The process of creating, evaluating, and revising hand-sketched drawings to represent an individual’s own ideas (i.e., not generated by comparison with canonical models) about science phenomena and therefore, is considered a form of modeling.

**Feature:** Term used to indicate the attributes or aspects of the PST-generated drawings, such as objects included in the drawing that were observable to the unaided eye or their ideas about non-observable science structures, processes, or relationships that explain the phenomenon.

**Field experience:** PSTs’ student teaching activities and interactions in assigned elementary classrooms under the guidance of mentor in-service elementary teachers as part of their teacher education program.

**Graphic symbol:** A visual symbol, such as an arrow, with a specific meaning that is conveyed without the use of text-based language.

**Interest:** An affective characteristic that reflects an individual’s disposition to learn more about or engage with an idea, object, or activity. Interest in this research does not
differentiate among the four phases of interest that have been conceptualized by Hidi and Renninger (2006). It is a learned characteristic (Anderson and Bourke, 2000) that is shaped by individual experiences.

**Learning outcome:** Measurable or self-reported changes of affective characteristics, science knowledge or pedagogical content knowledge because of learning activities.

**Mental model:** The internal representation (i.e., residing in one’s mind) of an individual’s understanding of a phenomenon.

**Modality:** The way in which information or ideas are expressed, which includes written text, aural text, and visual representation. Multi-modality refers to the use of multiple ways of expressing ideas and information.

**Model:** Based on an epistemological viewpoint as a tool for building science knowledge (Upmeir zu Belzen et al., 2019), models are external representations in a variety of forms, including drawings, and can serve the purpose of helping an individual to reason and make meaning about a science phenomenon.

**Metacognition:** An aspect of model use that addresses whether learners are self-aware of the quality and utility of their created models (Quillin and Thomas, 2015).

**Model relationships:** An aspect of model use that refers to the representational correspondence between a model and reality or among multiple models. Novice versus expert model users will differ in how they view the relationships between a model and reality (i.e., one-to-one vs many-to-one) and their ability to “translate among models on the same [representational] scale, and between models on different [representational] scales” (Quillin and Thomas, 2015, p.8).
**Modeling:** The iterative process of creating, evaluating, and revising a model to build knowledge and infer a causal explanation about an observed science phenomenon.

**Non-observable:** A structure, process, or relationship in a science phenomenon that is not observable by the unaided eye but is important for building an explanation for the observed phenomenon (e.g., a water molecule, molecular charge, cohesion between molecules, etc…).

**Observable:** A feature that can be seen by the unaided eye and is descriptive but not explanatory of a science phenomenon (e.g., water drop, washcloth, wringing motion, etc…).

**Pedagogical content knowledge (PCK):** Specialized knowledge that is necessary for effective science instruction and includes knowledge about students’ science ideas (both everyday and canonical views), instructional strategies, assessment, and curriculum.

**Process:** An ontological categorization of science concepts, which refers to non-material ideas like gravity and intermolecular water forces (Reiner et al., 2010) or systems of steps or events that explain an observed science phenomenon (e.g., balance of forces, pairs of forces, magnetism, etc…). This is one of the non-observable features that is assessed in the PST-generated drawings and written explanations.

**Purpose & salient features:** An aspect of model use based on Quillin and Thomas (2015) that addresses whether the individual views drawings as fixed with correct answers and includes mostly observable features in drawings or as thinking tools and includes non-observable structures, processes, and relationships.
**Relationship:** An ontological categorization of science concepts, which refers to how science concepts are interrelated in a way that causes an observed pattern (e.g., properties of different states of matter due to the spatial aspects of molecules). This is one of the non-observable features that is assessed in the PST-generated drawings and written explanations.

**Representation:** A physical or nonphysical entity that stands for something else. Examples include but are not limited to text-based signs and symbols, mathematical expressions, visual images, and physical models.

**Science knowledge (SK):** Based on Lehrer and Schauble’s (2015) framing of the development of scientific thinking as “science-as-practice” (p. 671), this term is used to include knowledge about both concepts about science structures, processes, and relationships, as well as science practices, such as drawing.

**Self-efficacy:** A multi-faceted, latent construct with affective, cognitive, and behavior components that indicates an individual’s belief in their ability to effectively engage with activities such as teaching or learning. It has been referred to colloquially to as a “can do” attitude. In this research it has been classified as an affective characteristic (Anderson and Bourke, 2000), because it involves an individual’s feelings that have directionality and intensity, has a target for the feelings (i.e. teaching, drawing, physical science knowledge), and is stable (i.e. considered a trait not a state). It is considered a learned characteristic (Anderson and Bourke, 2000) that is based on individual experiences, including mastery experiences, vicarious experiences, physiological feedback, and verbal persuasion (Bandura, 1997).
**Structure:** An ontological categorization of science concepts, which refers to a material object’s composition, spatial arrangement and organization of parts, and physical properties. This is one of the non-observable ideas that is assessed in the PST-generated drawings and written explanations.

**Translation:** A visual literacy skill that includes an individual’s ability to comprehend and to generate different visual, textual, or symbolic representations of ideas or objects. In this research translations include the ability to generate representations a) as both a visual image and as text (visual to text translation), b) as multiple visual images on the same scale (horizontal translation), and c) as multiple visual images on different scales (vertical translation). In this research, an example of horizontal translation was PSTs drawing different molecular representations for water. An example of vertical translation is drawing a representation for the visible liquid form of water along with a representation of water as a collection of spatially separated molecules.

**Value:** An affective characteristic that indicates an individual’s evaluation of the importance or acceptability of a targeted idea, object, or activity. Similar to attitudes, it is considered a learned characteristic (Anderson & Bourke, 2000), which involves feelings that are shaped by personal and social standards and experiences.

**Visual literacy:** The ability and knowledge to both interpret and create visual information for communication and learning.
CHAPTER 2

LITERATURE REVIEW

This chapter provides an overview of selected literature that was used for developing the conceptual framework for the research. The literature included in this chapter is comprehensive but is not an exhaustive compilation of educational research related to drawing and elementary PST education. To support the research focus on explicit instruction on drawing-to-reason during an elementary science methods course for PSTs, the literature on drawing includes a brief general background on drawing and its purposes in science and elementary education, research on drawing as a learning strategy, and drawing-to-reason as a science practice, including its use in modeling and the instructional framework by Quillin and Thomas (2015), which was the basis of instructional interventions used in this study. The literature on PSTs includes the relationship of affective characteristics, SK and PCK to teacher preparation for elementary science instruction to support the targeted learning outcomes for PSTs in this study. The chapter concludes with an overview of the conceptual framework, including its theoretical grounding and the conceptual and operationalized definitions of constructs used as measures of learning outcomes in this study.

Drawing

The literature summarized in this section provides a general overview of drawing, children’s use of drawing, and scientists’ use of drawing as an authentic practice to build and communicate knowledge. This literature review focuses only on educational research in which the drawings were generated by students, including elementary, secondary, or post-secondary students. While some literature has used the terminology of learner-generated drawings, this dissertation will use the terminology of student-generated drawings. For literature in which PSTs
or in-service teachers were the focus of the research study and generated the drawings, the terms PST-generated or teacher-generated drawings will be used distinguish them from students.

Overview

Drawing is considered a language modality (Cohn, 2012) and was used by humans for communication long before the development of written language (Tversky, 2001). The earliest known example of human drawing dates back 73,000 years to an abstract scribble made with an ochre crayon on stone, which was found in a cave in South Africa (Henshilwood et al., 2018). As alphabets used in written language became more widely disseminated and the printing press was used for reproducing and distributing written language, drawings became used most often for aesthetic purposes rather than communication (Tversky, 2001).

Based on Peirce’s triadic model of semiosis (Chandler, 2017), visual representations depicted in drawings are sign vehicles that are categorized as symbolic, iconic, indexical, or a combination of the three. Highly iconic sign vehicles in science drawings visually resemble their referential object; for example, a life-like depiction of animal anatomy or plant structure. Drawings with sign vehicles that are iconic have been used primarily for learning outcomes such as improved observation skills (Landin, 2011). Symbolic sign vehicles are more abstract and do not necessarily resemble their referential object, for example, the use of vectors to represent gravitational force or acceleration (Quillin & Thomas, 2015).

In the education research literature, there is a lack of commonality in language for visual representations that referred to as drawings in this study. Literature references for visual representations include “sketch, diagram, external representation, external model, visualization, illustration, [and] picture” (Quillin & Thomas, 2015, p. 2). In addition, the various terms for drawing in the literature have been used in research studies with visual representations that were
generated by an individual (Larkin & Simon, 1987), as well as studies with individuals using visual representations produced by others (Mayer & Gallini, 1990).

Drawings are defined as static, two-dimensional, visual representations generated by mark-making on medium to depict “any type of [science] content…[including] structure, relationship, or process” (Quillin & Thomas, 2015, p. 2). They may contain written text such as labels or legends to clarify visual information. Drawings as products are generated primarily to communicate a final, refined idea (Hope, 2008). Drawing as a process is defined as mark-making based on an individual’s ideas (i.e., not generated by comparison with canonical models and representations), so that drawings are “tools to think with” (Kindfield, 1994, p. 1). The focus of this research is on process-oriented drawing purposes of drawing to reason and to build knowledge about science phenomena. Drawing for this purpose is referred to as drawing-to-reason and is defined as the process of drawing in which a student or PST creates, evaluates, and revises hand-sketched drawings to create external, visual representations of their evolving ideas about science phenomena.

**Drawing and Children**

While this dissertation study is focused on the use of drawing to reason in science, this section briefly includes general information about the potential for drawing to support learning. Literature more specific to the science learning outcomes from drawing are included in this chapter’s section *Drawing as a Science Learning Strategy*.

Children naturally draw as a form of self-expression (Kress & van Leeuwen, 2006). While children enter school ready to draw (Anning, 1999), within a few years of formal education, they become self-conscious of their perceived drawing ability and begin to refrain from using it as part of their learning and communication. In education, a nativist view of
drawing as a form of self-expression and as developmentally independent of instruction traditionally has limited its role as a tool for learning (Duncum, 1999). Many elementary educators have ascribed to the Lowenfeld and Brittain’s (1975) theory of a series of developmental stages, which are viewed as independent of sociocultural influences, and discouraged instructional interventions for drawing during elementary grades. However, more recently, there has been increased attention to the conventionalist view of drawing as a process in children, which should be scaffolded and specifically taught recently because of its supportive role for meaning making in various disciplines (Adoniou, 2014).

Historically, reading and writing historically have been the privileged modes for building, representing, and communicating knowledge (Short & Kaufman, 2000) in the classroom. Hope (2008) has argued that a lack of drawing in the elementary classroom could be impeding children’s ability to think, reason and express their ideas. There is emerging research around the learning outcomes for students from the use of multimodal instructional practices (Kress, 2000), particularly for those who may struggle with traditional text-based materials (Wiseman et al., 2017). Drawing allows children to express their ideas without worrying about writing mechanics, spelling or punctuation. Everything can be inscribed without constraints on the order or organization on the page, and the inscriptions are placeholders for evolving ideas that can readily be changed.

This more recent interest supporting diverse learners in the classroom has brought attention to the role that drawing may play for communication and meaning-making in the classroom. Research supports the role of drawing in emergent writing (MacKenzie, 2011). MacKenzie argues that children should be engaged with both as a unified system of communication in the classroom versus as using them separate and unrelated forms of
expression. Adoniou (2013; 2014) found that elementary students who drew procedural and explanatory information improved their quality of writing based on linguistic criteria for the organization and content of the entire text, the syntax of their sentences, and vocabulary usage. Writing artefacts from students who drew prior to writing included more of the required structural text such as title and ingredients, had more complex sentence structure, and used a wider breadth of appropriate vocabulary.

The multimodal benefits of drawing with text extend beyond the elementary grades. For example, Akaygun and Jones (2014) found that both written and visual representations supported undergraduate students’ ability to communicate their understanding of equilibrium. The students used drawings for communicating ideas related to structural information and written text for processes. Tversky (2001) noted that while visual representation can facilitate information processing, the meaning of symbols is not always clear, and individuals need written text as support.

**Drawing as an Authentic Science Practice**

Scientists use visual representations to record observations, explore theories, illustrate explanations, and communicate internally within the scientific community, as well as externally to the public (Ainsworth et al., 2011). According to Latour (1990), scientist-generated drawings have influenced the evolution of accepted models for science phenomena and served as the impetus for pursuing new science knowledge through research.

The key role of visual representations in understanding and communicating science concepts has not been mirrored in instructional practices of the elementary classroom, where reading and writing historically have been the privileged modes for building and representing knowledge (Short and Kaufman, 2008). Clement (1989) pointed out that teachers tend to focus
on empirical laws and quantitative formulas as being evidence of what they would define as science, but instead need to focus on “activities that are aimed at forming explanatory models” (p. 380). Students and teachers need to engage in authentic scientific practices such as drawing in the classroom as they build their conceptual understanding about the world around them (Lehrer & Schaub, 2015). However, teachers often have limited experience incorporating modeling in the classroom (Leavens et al., 2021), and are likely to default to practices with which they are comfortable (Appleton, 2003).

**Drawing as a Science Learning Strategy**

This section summarizes representative literature references on research with drawing as a learning strategy in science. It includes subsections for (a) theoretical framing of the process of learning from science drawing, (b) purposes of drawing as a learning strategy in elementary science, (c) drawing-to-reason as a form of modeling in science, and (d) Quillin and Thomas’s (2015) instructional framework for drawing-to-reason.

**Theoretical Framing for Process of Learning with Drawings**

There are various processes through which drawing has been argued to support student learning. This section of the theoretical framing for research on the process of learning is organized based Wu and Rao’s (2019) review. It summarizes the six processes for learning from science drawings and provides an example study for elementary students when available.

Based on literature, Wu and Rao (2019) divided the learning processes from drawing into either cognitivist or sociocultural theoretical frameworks. The cognitivist framework included the processes of generative learning, self-regulation, mental model integration, and spatial cognition. The sociocultural processes included mediated discourse and disciplinary practices. While Wu and Rao (2019) described the processes as distinct, they conceptualized them as
interrelated and to build upon each other. For example, generative learning was viewed as foundational to the other three cognitive processes, and the cognitive processes were viewed as foundational for the sociocultural processes.

Learning from drawing can occur through the process of generative learning based on van Meter (2001) generative theory of drawing construction in which learners are selecting, organizing, and integrating textual information to create a visual representation. This process of learning was noted in Eden and Potter’s (2003) study with fourth and fifth graders learning about the conservation of energy. Students who had generated drawings based on their understanding of expository text had higher post-test gains on assessments compared to the students who read expository text and created written science or copied an illustration. This is one of the most common purposes for incorporation of drawing as a learning strategy (Fiorella & Zhang, 2018; van Meter & Garner, 2005). While some researchers have reported that drawing did not influence learning outcomes, both Fiorella and Zhang (2018) and van Meter & Garner (2005) have identified factors such as the need for instructional guidance, attention to inclusion of accurate details, and use of higher-order assessments to differentiate the benefits of drawing as a generative learning strategy.

Drawing can support the process of self-regulated learning by engaging students with the content and the drawing activity. Self-regulated learning refers to students’ ability to self-assess their understanding of content and direct their learning to increase their knowledge. Hellenbrand et al. (2019) tracked the eye movements of eighth and ninth grade German students who were tasked to either draw pictures based on expository text about the influenza virus as they were reading versus students who just read text that also included illustrations. The eye movement of the students in the drawing group indicated more rereading of the text while generating their
drawings, and they had significantly higher post-reading scores on the retention test and a drawing test on the text content. Hellebrand et al. attributed the learning outcomes to the influence of drawing on their metacognitive awareness while reading.

Drawing supports the process of learning by mental model integration as students create, evaluate, and revise initial drawings to incorporate new knowledge from lessons, participate in class discourse, or compare with authoritative illustrations. Creating a drawing activates the students’ internal, mental models, and conceptual change occurs as the students evaluate and revise their initial ideas. Drawings serve as epistemic mediators (Magnani, 1985), which will help students both mirror their internal mental representations of the explanation for science phenomena and unveil conceptual changes. The students in a study by Williams et. al. (2019) learned through the process of conceptual change as they used drawing to reason about a phenomenon based on inertia. Students created drawings based on their initial ideas, which they re-iteratively evaluated and revised based on lesson activities, student discussion, and teachers prompts.

Spatial cognition refers to the process through which drawings help students make sense of four different structural relations, including visual, spatial, causal, and temporal. Visual refers to meaning making about shapes or aesthetic features of objects or structures, such as anatomical features of the body. Spatial refers to meaning making about relative distance and size, for example relative density of molecules in distinct types of matter. Causal relations help students understand how objects or entities can influence each other. For example, how the angle of sunlight changes depending on its position in the sky. Finally temporal refers to understanding changes over time such as the phases of the moon. Drawing has been shown to be a valuable
learning tool in learning chemistry because it supports students’ understanding of concepts like matter, solutions, and equilibrium (Cooper et al., 2017).

Wu and Rao (2019) point out that the sociocultural-framed processes build on the cognitive processes. In addition, for both mediated discourse and disciplinary practice, the learning goals include both the process of using the drawing as well as the learning outcome from engaging with it.

Mediated discourse is the process of using drawing as a tool for communication that facilitates discussion of ideas around science content within the classroom. An example of this learning process is the study by Williams et. al. (2019) in which the students used their drawings about inertia as part of their small group and classroom discussions. Drawing to communicate provided the students with the opportunity to learn discipline-specific visual conventions to effectively communicate their ideas with others in the class.

Disciplinary practice is the use of drawing for meaning-making about phenomena that enculturates students into the field of science. It supports building the students’ conceptual knowledge, while also supporting their understanding of what scientists do and how scientists build knowledge about the world. Wu and Rao (2019) focus on Prain and Tytler’s (2012) Representational Construction Affordances (RCA) framework for the sociocultural perspective. The RCA framework includes three interrelated dimensions, termed semiotic, epistemic, and epistemological, to explain the ways in which students build scientific knowledge and benefit from engaging with student-generated representations. Briefly, the semiotic dimension is based on Peirce’s triadic model of representamen, object, and interpretant (Peirce, 1960) and frames how symbolic tools, such as mathematical equations, graphs, or images, and material tools, such as instruments or physical artefacts, support student learning. The epistemic dimension focuses
on how integration of different representations in science classrooms supports students’ knowledge-building, and the epistemological dimension focuses on how the use of representations influence students’ ways of knowing about science.

**Drawing Purposes in Elementary Science Education**

Researchers have outlined several purposes for incorporation of drawing in the classroom based on reviews of the literature (Ainsworth, 2011; Fan, 2015). For the elementary grades, Ainsworth et al. (2011) identified five distinct reasons for incorporation of student-generated drawings to support science instruction, including to (a) learn content, (b) support students’ communication, (c) engage students, (d) learn different representational types, and (e) reason about science phenomena. These purposes can be categorized as ranging from product-oriented to process-oriented (Hope, 2008). For purposes that are more product-oriented, the focus of the learning is based on the final drawing. What the students have depicted in their final drawing is the objective for the learning. For purposes that are more process-oriented, it is the act of drawing that is the focus for learning. The objective is for students to learn through their process of drawing. While these five purposes for drawing are defined as distinct with different objectives, all of them are valuable instructional strategies in the classroom.

Drawing for used for the purpose of learning includes activities such as concept mapping to make connections among ideas, observational drawing to focus attention on details of structure and function, labeling drawings to facilitate fact memorization or vocabulary acquisition, and visual summarization of textual information. Communicating with drawings include activities in which they are used as an alternate or supplemental modality to help students express their ideas during small group or classroom discourse or as a formative or summative assessment of students’ recall of information or understanding of lesson content.
Engagement purposes motivate students to learn content through a modality they enjoy. Science knowledge is constructed and expressed via multiple, integrated modalities, including visual representation. Drawing generation allows students to learn about and to actively practice visual conventions for representing scientific ideas. This representation experience and knowledge supports using drawings for reasoning to generate explanations about science phenomena. Drawing used for reasoning is a form of the authentic science practice of modeling and builds students’ science knowledge as they create, use, evaluate and revise their drawings.

As mentioned, the purposes of drawing were outlined by Ainsworth et al. (2011) as distinct, however, inclusion of drawing in the classroom will often target multiple purposes (Edens & Potter, 2003; Williams et. al., 2019). Edens and Potter (2003) examined the role of student-generated drawings on fourth and fifth grade elementary students’ understanding of the conservation of energy related to slides and roller coasters. One purpose for inclusion of drawing in their study was to learn content. Students read expository text and created science logs either by writing what they learned, copying an illustration depicting the text, or generating their own drawings of their understandings from the text. They also used drawing for the purpose of communication, because one of the assessments for conceptual knowledge after the lessons was based on the number and accuracy of concepts included in their drawings. In their study, students who generated drawings after reading had higher post-test gains in assessments that contained questions for factual recall as well as synthesis of ideas. Williams et. al. (2019) incorporated drawing for communication and for reasoning in the elementary classroom. They used a case-study approach with ten elementary students in a bilingual school in Hong Kong to investigate English language students’ science understandings from multimodal, inquiry-based classroom lessons on force and motion. The multimodal lessons used verbal, drawn and written
representations to build explanations for the Newton’s bottle phenomenon, which illustrates inertia (Hoover, 2018). Drawings were used as part of the reasoning process in which students re-iteratively evaluated and revised their ideas based on lesson activities, student discussion, and teachers prompts. The student drawings also were used in connection to their speech and gesturing to support their communication during class discussions. Williams et al found that an increased use of scientific vocabulary correlated with drawing revisions and meaning-making during the lessons.

Education researchers also have used drawing as a research tool for understanding children’s science ideas (Özsoy, 2012; Rennie & Jarvis, 1995; Villarroel & Ros, 2013). Özsoy (2012) used drawing to investigate the prior knowledge of first grade, Turkish school children (ages 6 to 8 years-old) about the shape of Earth. The researchers wanted to determine if their first graders conceptualized Earth as a spherical planet or as a flat area that was consistent with their everyday, lived experiences. Students’ drawings and interviews were coded deductively for depiction of earth, stars, and moon. The research findings support the value of students’ verbal descriptions for interpreting children’s drawings of their science understanding. The drawings showed three categories of student understandings for the earth, including spherical, flat earth, and dual earth (both spherical and flat). However, when the students were interviewed, they discussed it was round and the ones who drew a flat earth or dual earth had wanted to be able to include details such as depicting people on earth. Rennie and Jarvis (1995) assessed primary school students’ concepts of technology based on student-generated drawings and writings. Deductive content analysis was used to evaluate students’ ideas for the definition of technology and attitudes about it. The authors noted age-related complexity in the students’ concepts about technology, which they concluded was related to experiences with technology versus
development differences in knowledge. Like Özsoy (2012), Rennie and Jarvis found that student interviews were important for accurate interpretation of the student drawings. Villarroel and Ros (2013) used student-generated drawings and semi-structured interviews to compare young children’s understanding of the water cycle with age. The study population included preschool and first year primary students (ages 5 to 7 years-old) from the Basque Autonomous Community on the Iberian Peninsula. Two different age groups were used to determine if differences in conceptual understandings would be evident in either drawn or oral explanations. The students’ drawings, but not their interviews, revealed age-related differences in their understanding of the water cycle. The first-year primary students were more likely than the preschoolers to draw the sun and bodies of water as important parts of the water cycle, but both groups mentioned the sun frequently during their interviews. Only the first-year primary students referred to the sun as a heat source in the cycle and versus an unrelated object in the sky.

Recent science education studies have argued for the value of including drawing with other modes of assessment to provide a more extensive assessment of students’ science ideas. Stieff and DeSutter (2021) discussed that the learning gains from sketching in chemistry are not necessarily captured by traditional, multiple-choice assessments. In their study, students who participated in a chemistry curriculum that included sketching as a modeling activity were more likely to include sketches of their ideas on assessments and to have more canonically accurate sketches, such as inclusion of the dynamics of particle movement, than students who did not have instructional support for sketching. Cooper et al. (2015; 2017) reported that drawings produced by undergraduates in STEM majors provided more robust information about their understanding of intermolecular water forces compared with their written explanations. Cooper
and colleagues attributed it to the students’ abilities to use drawing to depict structural and spatial information that is relevant for understanding cohesion and adhesion.

While the education research with teachers and drawings appears to be limited predominately to assessing beliefs about science and science teaching (Minogue, 2010; Mensah, 2011), which is outside the scope of the current research, there are several recent studies that have used PST-generated drawing to assess their SK (Aydeniz & Brown, 2010; Harrell et al., 2022). Aydeniz and Brown (2010) found that PSTs’ drawings provided a better understanding about their conceptual ideas regarding electrical circuits, lunar phases, and seasonal changes. They used initial drawings to identify a range of alternate conceptions that the PSTs had at the beginning of a science methods course. Their methods course incorporated a series of hands-on activities and discussions targeting relevant content to address the PSTs’ conceptions. Comparison of pre- and post-lesson drawings indicated changes in the PSTs’ ideas during the course. Harrell et al. (2022) used drawing as one form of assessment for PSTs’ understanding of buoyant force after instructional interventions based on the 5E learning cycle to target SK during their science methods course. At the end of the lessons, PSTs were asked to draw a depiction of a boat floating on water with all associated forces acting on it. The drawings showed gains in PSTs’ understanding of the roles of opposing forces and surface area in buoyancy.

**Drawing-to-Reason**

As described by Ainsworth et al. (2011) one of the purposes for drawing in science is as a tool to make meaning about science phenomena. This meaning-making process involves students creating, evaluating, and revising hand-sketched drawings to represent their own ideas (i.e., not generated by comparison with canonical models) about science phenomena. In this research, this drawing process is referred to as *drawing-to-reason* and considered a form of science modeling.
Models are authentic forms of science practice and serve as explanations that subsume other forms of science practice such as argumentation, questioning, analyzing, and interpreting data, using computational and mathematical thinking, and obtaining, evaluating, and communicating information (Lehrer & Schauble, 2015). Models provide simplifications of phenomena that otherwise would be too complex to comprehend. While science philosophers debate the ontological definition of models (Contessa, 2007; Frigg & Nguyen, 2017), they do recognize a range of forms that they can take, including drawing, and the role that models play in building science knowledge (Harrison & Treagust, 2000). When students participate in the process of constructing representations as an explanation for a phenomenon, they are engaging in the same practices as scientists (Clement, 1989) who cycle through a continuous process of construction, evaluation, and modification. This section focuses on learning outcomes for elementary students includes extant literature on drawing-to-reason specifically, as well as literature on modeling when drawing was the referenced form used in the study.

**Quillin and Thomas's Instructional Framework for Drawing-to-Reason**

Explicit instruction on science drawing has been argued to be important for student learning outcomes (Fiorella & Zhang, 2018; van Meter & Garner, 2005). However, in their review of the use of drawing for learning in biology, Quillin and Thomas (2015) noted that most instructors did not intentionally teach the process of drawing in their courses. They argued for incorporation of drawing in undergraduate courses because it mirrors the authentic practices of scientists to build conceptual knowledge and the need to provide explicit guidance for students.

Therefore, Quillin and Thomas proposed an instructional framework that could be implemented in the biology classroom to help undergraduate students develop drawing knowledge and skills. They focused on the use of drawing for model-based reasoning, which is
referred to in this study as drawing-to-reason. The instructional interventions in the framework were categorized as affective, visual literacy and modeling. Quillin and Thomas (2015) proposed three categories of instructional interventions for guiding students’ more expert use of drawing-to-reason, including affective, visual literacy, and modeling. To ground their instructional framework, they used cognitive load theory (Sweller, 1988; de Jong, 2010), which addresses the role that individual’s working memory plays in information processing and learning. The goal is to design instructional resources that minimize distractions to the information to be learned.

Quillin and Thomas (2015) conceptualized their framework as a sequence of instructions starting with affective interventions to focus the students’ attention on the drawing, which they posited would increase their motivation to draw and result in increased attention to the visual literacy interventions. The visual literacy interventions targeted support of students’ knowledge of common symbols used for biological representations and discernment of relevant versus extraneous features to include in their explanatory drawings. The visual literacy interventions would allow students to focus on biological concepts versus using working memory to determine how to draw their ideas. The last step in the interventions was the modeling process in which students engage in the cyclic process of creating, using, evaluating, and revising explanations for phenomena. Practice with modeling supports students’ metacognitive awareness of their knowledge and encourages use of drawing-to-reason for problem-solving. In the diagram for the instructional framework (Quillin & Thomas, Figure 6, p.11), they included influential feedback from the visual literacy and modeling on the affective interventions, as well as influential feedback from the modeling on visual literacy. While not discussed in the text, the arrows indicating recursive feedback are presumed to indicate that learning outcomes from drawing-to-
reason are influenced by all three categories of interventions. The specific interventions are described below.

Inclusion of affective interventions recognizes learning as intertwined with affect (Anderson & Bourke, 2000). Affect involves feelings and emotions directed towards a target. Quillin and Thomas’s (2015) proposed interventions to target four affective characteristics that have been identified by Anderson and Bourke (2000) as relevant to assess as learning outcomes in schools. The interventions targeted attitude, interest, self-efficacy, and value.

Quillin and Thomas (2015) defined visual literacy as “the ability of students both to interpret visual representations that are provided by instructors and also to create visual representations on their own” (p. 2), which is based on Schönborn and Anderson (2010). The concept of visual literacy has evolved from an eclectic mix of theories and disciplines, including linguistics, art, psychology, and philosophy (Hortin, 1994). In the current digital world, which is image rich, visual literacy is considered as important as verbal literacy for a 21st century skill. Visual literacy is multidisciplinary; the context in which images are created or used will matter.

Modeling is a process of creating, using, evaluating, and revising representations for phenomenon to understand the underlying causal mechanisms or to make predictions about it (Schwarz et al., 2009). It is an essential process in science for building knowledge by refining ideas based on initial claims, comparison with evidence. While there are various representational forms that can be used for modeling, in this study the focus is on modeling with drawings.

The intervention categories reflect the process-oriented purposes for drawing outlined by Ainsworth et al. (2015). For example, the affective interventions for drawing are meant to engage students with drawing, and the visual literacy interventions support students’ use of drawing to learn to represent in science. The modeling intervention supports student to reason
through the creation, evaluations, and revision of drawings to build explanations for science phenomena. Although the interventions reflect different drawing purposes individually, collectively they are meant to support students’ reasoning, and therefore, are referred to as explicit instruction on drawing-to-reason for the purposes of this study.

In addition to defining instruction interventions, Quillin and Thomas outlined seven aspects of model use that could be used to differentiate between experts and novice users of drawing-to-reason. They pointed to the need for establishing learning goals for the use of drawing-to-reason in the classroom. The seven aspects were based on their review of the extant literature for the purposes of models in the various STEM disciplines and how experts used them to build knowledge. The seven aspects included (a) model relationship to reality, (b) model relationship to other models, (c) salient features, (d) flexibility, (e) purpose, (f) spontaneous use, and (g) metacognition. According to Quillin and Thomas’ criteria, expert learners will display characteristics consistent with scientists’ use of models for building science knowledge. Novice learners will develop more expertise with models as they engage with them for their own learning. The definitions from Quillin and Thomas (2015 for each of the aspects based on novice versus expert use are provided in Table 2.1.
**Table 2.1**

*Drawing-to-Reason Novice Versus Expert Use (Quillin & Thomas, 2015, Table 5)*

<table>
<thead>
<tr>
<th>Aspect of models</th>
<th>Novice learners</th>
<th>Expert learners</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relationship to reality</td>
<td>“Think there is a 1:1 correspondence between models and reality”</td>
<td>“Understand that no model is wholly right, so multiple models should be used”</td>
</tr>
<tr>
<td></td>
<td>“Struggle to translate among multiple models at the same scale, and between models at different scales”</td>
<td>“Can easily translate among multiple models”</td>
</tr>
<tr>
<td>Relationship to other models</td>
<td>“Tend to focus on surface features of the models (such as model organism used or other case study context)”</td>
<td>“Tend to focus on underlying relationships, processes, functions, and principles in the models”</td>
</tr>
<tr>
<td>Salient features</td>
<td>“View models as static and fixed”</td>
<td>“View models as dynamic tools that can be manipulated and changed”</td>
</tr>
<tr>
<td>Purpose</td>
<td>“View models as endpoints that are right and can be memorized as facts”</td>
<td>“View models as thinking tools”</td>
</tr>
<tr>
<td>Spontaneous use</td>
<td>“Tend not to make their own models to solve problems unless explicitly instructed to do so”</td>
<td>“Tend to make models spontaneously to solve problems on their own”</td>
</tr>
<tr>
<td>Metacognition</td>
<td>“When creating models, tend not to be self-aware of the quality or utility of their models”</td>
<td>“When creating models, can evaluate the quality or utility of their models”</td>
</tr>
</tbody>
</table>
Upmeier zu Belzen et al. (2019) proposed a framework of modeling competency to use in the field of science education as a guide for the use of models by students, PSTs, and in-service teachers. Their framework consisted of five model use aspects, including nature of models, multiple models, purpose of models, testing models, and changing models. Each of the five aspects had three progressive levels that they based the concept of model-being proposed by Mahr (2015 as cited by Upmeier zu Belzen et al., 2019). Model-being refers to the idea of what makes an object or representation a model. They noted that the proposed structure should be considered nominal, because although based on literature, it had not been validated empirically. The criteria for each level of the five aspects are listed in Table 2.2. The progression of levels represents the views or use of models by the student, PST or in-service teacher based on the particular aspect of model competence.

Table 2.2

Framework for Modeling Competence (Upmeier zu Belzen et al., 2019, Figure 1.3)

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Level I</th>
<th>Level II</th>
<th>Level III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nature of models</td>
<td>“Replication of the phenomenon”</td>
<td>“Idealized representation of the phenomenon”</td>
<td>“Theoretical reconstruction of the phenomenon”</td>
</tr>
<tr>
<td>Multiple models</td>
<td>“Different model objects”</td>
<td>“Different foci on the phenomenon”</td>
<td>“Different hypothesis about the phenomenon”</td>
</tr>
<tr>
<td>Purpose of models</td>
<td>“Describing the phenomenon”</td>
<td>“Explaining the phenomenon”</td>
<td>“Predicting something about the phenomenon”</td>
</tr>
<tr>
<td>Testing models</td>
<td>“Testing the model object”</td>
<td>“Comparing the model and the phenomenon”</td>
<td>“Testing hypothesis about the phenomenon”</td>
</tr>
<tr>
<td>Changing models</td>
<td>“Correcting defects in the model object”</td>
<td>“Revising due to new insights”</td>
<td>“Revising due to the falsification of hypotheses about the phenomenon”</td>
</tr>
</tbody>
</table>
Preparation of Elementary Preservice Teachers for Science Instruction

This section summarizes literature regarding (a) elementary teachers’ use and knowledge of drawing in the elementary science classroom, (b) factors that influence elementary teachers’ science instructional strategies, and (c) the role of teacher education in preparing elementary teachers for science instruction, particularly drawing as an instructional strategy.

Elementary Teachers’ Use and Knowledge of Science Drawing

This section summarizes literature both regarding elementary teachers’ knowledge and instructional use of science drawings, as well as relevant literature on science modeling to add context.

The significant role of models, including drawing-to-reason, for understanding science concepts has not been mirrored in instructional practices of the elementary classroom (Lehrer and Schauble, 2000). The Framework for K-12 Science Education (NRC, 2012) includes scientific and engineering practices along with crosscutting concepts across science and engineering and core ideas of specific science disciplines as the three major dimensions around which education should be structured in grades K–12. One of the recommended practices is the development and use of models in the science classroom. Lehrer and Schauble (2015) have argued for the prioritization of modeling in the classroom because the process incorporates many of the other practices, including asking questions; planning and conducting investigations, analyzing and interpreting data, using mathematical and computational thinking, constructing explanations, engaging in evidence-based argumentation, and obtaining, valuating and communicating information.

While 95% of elementary teachers agreed that students should learn science through practices, in the 2018 National Survey on Science and Mathematics Educators (NSSME), only
26% of surveyed elementary students across the United States indicated their instructional objectives included an emphasis on developing students’ abilities to do science, including having students develop scientific questions; design and conduct investigations; analyze data; and develop models, explanations and scientific arguments (Banilower, 2018). In addition, only 19% of elementary teachers had their students engage at least once per week with the practice of developing scientific models, including physical, graphical (i.e., drawings) and mathematical representations of science phenomena (Plumley, 2019). While the elementary teachers expressed beliefs consistent with instruction recommended by the Framework for K-12 Science Education (NRC, 2012), the majority of elementary teachers still expressed agreement with instructional practices that are not recommended by NRC such as front-loading vocabulary (77%) and using hands-on activities to reinforce already learned concepts (56%). Coleman et al. (2011) surveyed elementary teachers across the United States for their incorporation and instructional practices with graphical representations in the classroom based on Moline’s (1995) classification system of diverse types of diagrams, graphs, maps, tables, and timelines. The least frequently incorporated practice was students’ generation of their own drawings. Only 6% of the surveyed teachers incorporated student-generated drawing frequently in the classroom, and 73% indicated that they rarely or never incorporated them as a practice.

The lack of incorporation of model-related practices like drawing in the elementary classroom may reflect the teachers’ lack of preparation for how to incorporate them in the classroom. Based on the 2018 NSMME responses (Banilower, 2018), only 17% of surveyed elementary students across the United States indicated that they felt prepared to develop students’ abilities to do science, including having students develop scientific questions; design and conduct investigations; analyze data; and develop models, explanations, and scientific
arguments. Windschitl and Thompson (2006) discuss how teachers’ lack of knowledge about the role of models for building science knowledge likely reflects their prior educational experiences. They noted research that teachers’ undergraduate science content courses as part of their teacher education programs are often lecture-based or just include confirmatory not inquiry-based laboratory activities (Bowen & Roth, 1998; Duschl & Grandy, 2005; King, 1994; Trumbull & Kerr, 1993; Wend & Smith, 2004 as cited by Windschitl & Thompson, 2006). Teachers’ educational experiences have contributed to their views of models more for the purpose of communicating or learning established facts about science, versus their purpose as a tool to build conceptual understanding about science phenomena.

Supporting teachers’ knowledge and use of drawing-to-reason in the elementary classroom has been shown to influence students’ learning outcomes (Zangori et al., 2015; 2017). Zangori and colleagues incorporated drawing-to-reason in third grade classrooms to support the students’ engagement with modeling and to use it as a tool to build knowledge about the water cycle. Drawing-to-reason was incorporated into a unit of lessons in which students were generating explanations for a hydrologic phenomenon that affected underground water. The teachers in the classrooms had a range of teaching experience (0 to 22 years) but had not participated in professional development or had teacher education preparation on the use of models as an instructional strategy in science. Between the first and second year of the project, the teachers participated in a workshop to gain instructional experience with drawing to reason as part of their science instruction. The workshop supported the teachers to learn about how modeling is important for student learning, the practices of modeling (create, use, evaluate, revise), and the elements of model-based explanation.
Both in year one and two of the project, the researchers evaluated students’ drawings of their explanation for the water phenomenon with a learning performance continuum instrument. The performance continuum had been developed previously by the researchers in prior research (Forbes et al., 2015; Schwarz et al., 2009) and included five elements that they had identified empirically as important for mechanism-based explanations of phenomenon. In year one before the teacher workshop, researchers observed that all the teachers were focused on having students generate drawings that looked like the water cycle versus helping students incorporate underlying mechanisms in their drawings. However, in year two after the teacher workshop, more students generated mechanism-based explanations for the water phenomenon. Conceptual gains about water cycling, which were based on coding student drawings according to the learning performance continuum, were greatest for students in two classrooms with teachers who provided more instructional support and scaffolding of the drawing process.

Recent studies with early elementary teachers have demonstrated a need for teacher preparation on the use of drawing in science instruction. Areljung et al. (2021) used activity theory to explore how early childhood teachers in Sweden incorporated drawing in their classrooms. They found that most of the teachers viewed drawing as a general tool to support learning or communication in the classroom but did not consider it as a learning strategy for science. For the small subgroup of teachers who did incorporate drawing in their science lessons, most did not provide explicit support for their students’ use of drawing. Areljung and colleagues recommended the need for teacher education and professional development for drawing as an instructional strategy in science based on their findings.
Factors That Influence Elementary Teachers’ Science Instructional Strategies

Teachers are a key factor in students’ achievement (Darling-Hammond, 2000), and limitations in how prepared teachers feel to teach science have been shown to influence their teaching practices, including the extent and type of science lessons incorporated in the classroom (Appleton, 2003).

Korthagen (2017) posited that teacher learning (both preservice and in-service) is influenced by cognitive, affective, and motivational factors. The paper asserts that professional development needs all three factors to be effective based on their analysis of studies on teacher outcomes. For example, professional development described as the traditional theory to practice was argued to have a disconnect between the intellectual underpinnings for the training and teachers’ practical enactment, because is only focuses on the cognitive factor. The importance of multiple factors for teachers’ instructional preparation for science also is reflected in Desimone’s (2009) pathway model in which attitudes, beliefs and knowledge are considered important outcomes from professional development, which lead to instructional changes in the classroom and student academic outcomes.

In this dissertation the term affective characteristics has been used to include constructs which have an affective component, and for the purposes of this research, to include teachers’ attitudes, interest, beliefs, and self-efficacy. This terminology is consistent with Quillin and Thomas’s (2015) instructional framework and is based on Anderson and Bourke’s (2000) guidance for the assessment of affect-related learning outcomes in schools, which was used as the basis to define attitude, interest, self-efficacy, and value for this research. As discussed in the section on Quillin and Thomas’ (2015) instructional framework, affective characteristics are directed towards an object, activity, or idea. The literature presented below focuses on what is
known about elementary teachers’ affective characteristics towards science drawing, physical science, or science teaching in relation to their science instructional strategies.

One challenge with summarizing research on teachers’ attitudes towards science is the lack of a common conceptualization for the construct (Jones & Leagon, 2014; Osborne et al., 2003). In Osborne and colleagues’ (2003) review of extant literature, they noted that while “attitudes towards science” (Osborne, 2003, p 1053) have been a subject of research at the time for over 30 years, there was not a unifying theoretical framework or consensus definition for what is meant by the term. Allport (1935 as cited in Fishbein & Ajzen, 2009), a social psychologist, proposed attitude as a mental construct that predicted behavior regarding objects, activities, or people. His defined the individual trait of attitude as “a mental and neural state of readiness, organized through experience, exerting a directive and dynamic influence upon the individual’s response to all objects and situations with which it is related” (Allport, 1935, p. 810 as cited by Fishbein & Ajzen, 2009, p. 76). Eagly and Chaiken (1993) similarly advocated for an abstract and broadly inclusive term in which attitude is defined as “a psychological tendency that is expressed by evaluating a particular entity with some degree of favor or disfavor” (p. 1).

In contrast, Osborne (2003) included “feelings, beliefs, and values” (p.1053) under the umbrella of attitudes toward science. They posited that attitude is not a single construct but is instead composed of multiple subconstructs that represent distinct factors for whether an individual will feel favorable or disfavorable towards the field of science. The list of subconstructs in Osborne and colleagues’ conceptualization of attitude includes constructs that have been theorized as separate affective characteristics by other researchers, including self-efficacy (Bandura, 1997; Unfried & Pajares, 2020), self-esteem, value, and motivation. Van Aalderen-Smeets et al. (2012) divided attitude into personal versus professional attitude, which
they described as a tripartite model with cognitive beliefs, affective states, and perceived control elements.

The one commonality among the various conceptualizations of attitude is their connection to feelings and emotions, which influence an individual's learning and behaviors. This research uses Anderson and Bourke’s (2000) definition of attitude as liking versus disliking an activity, idea, or object, which was based on Ajzen and Fishbein’s theory of reasoned action (Fishbein & Ajzen, 2009, Chapter 3). Therefore, in this study teachers’ attitudes were related to their like or dislike of drawing, physical science, or science teaching.

Research has reported that elementary teachers tend to report negative attitudes towards physical science because of their perception regarding its difficulty (Johnston & Ahtee, 2006). Johnston & Ahtee (2006) found Finnish elementary PSTs and English elementary PSTs reported negative attitudes towards physics based on their responses in a semantic differential attitude instrument, particularly for the factor from the instrument attributed to perceived difficulty. The authors speculated that the more negative responses for the Finnish PSTs may reflect their prior educational experiences since Finland schools place more emphasis on the life and earth sciences.

Another important affective characteristic that influences classroom instruction is teacher self-efficacy (Zee & Koomen, 2016). Development of self-efficacy has been theorized to be influenced by four factors, mastery experiences, vicarious experiences, social influences, and physiological state (Bandura, 1997). Mastery experiences are considered the most influential factor on self-efficacy. The experience of participating in a task and succeeding builds upon itself, particularly when the tasks are perceived as challenging, and the individual can attribute success to their own efforts. Vicarious experiences refer to learning by observing others doing a
similar task. This is not as influential as mastery experiences, but individuals judge their ability to successfully perform their task by comparing themselves with others whom they perceive to be like them. Social persuasion encompasses both verbal and nonverbal judgements from outside sources, which can be either positive or negative. As proposed by Bandura (1997), social persuasion acts in concert with other factors to create confidence. An individual’s physiological state, such as anxiety, stress, immediate interest, and mood also influence their development of self-efficacy contributing to engagement and motivation with a task.

Teachers’ beliefs concerning their efficacy in the classroom have been found to “affect their general orientation toward the educational process as well as their specific instructional activities” (Bandura, 1997, p. 241). Bandura (1977) made a distinction between two constructs in teachers’ self-efficacy towards teaching. The first construct was teachers’ beliefs in their ability to facilitate instruction in the classroom. The second construct was teachers’ beliefs that their instruction would influence student learning outcomes. This research focuses on teachers’ beliefs regarding their ability to facilitate science instruction, which will be referred to as science teaching self-efficacy beliefs (STEB).

Elementary teachers’ STEB has been associated with instructional practices incorporated in the classroom and with student learning outcomes (Lakshmanan et al., 2011; Lumpe et al., 2012; Vallinder, 1994). Vallinder (1994) found that special education teachers with higher self-reported STEB based on Gibson and Dembo (1984) teacher efficacy scale also reported the willingness to try a greater variety of instructional strategies in the classroom. In science education specifically, elementary, and secondary teachers who participated in both content knowledge courses and professional learning communities over a three-year period of time, demonstrated significantly increased STEB that was correlated with incorporation of more
reformed-based practices, such as student-centered instruction and use of models, in the classroom based on observations (Lakshaman et al., 2011). Lumpe et al. (2012) reported that elementary teachers’ STEB following an intensive science professional development program (>100 hrs) was positively correlated with their students’ science achievement based on standardized state tests.

While teachers’ attitudes and beliefs are influential on their instruction, elementary teachers also need a strong SK and PCK foundation to effectively facilitate science instruction in the classroom. In their standards for science teacher preparation, NSTA has recommended that teacher education programs prepare teachers to include a variety of instructional strategies that would engage students in science practices as part of their PCK preparation and that they demonstrate science practices as part of their SK (Morrell et al., 2020). The extent of SK may limit an elementary teacher’s ability to monitor student understanding and may influence whether the teacher uses ineffective didactic practices that focus on memorization of facts and the perceived “right” answer (Gomez-Zwiep, 2008) versus pedagogical practices that allow students to construct meaning during inquiry (Windschitl, 2002). Elementary teachers cannot effectively bridge the gap between students’ prior conceptions in science and more accurate internal mental representations, if they are limited in their own content knowledge (Yip, 1998). Ball (2000) noted that teachers’ “understanding [of] subject matter is essential to listening flexibly to others and hearing what they are saying or where they might be heading” (p. 242).

For the purposes of this research, SK has been divided into knowledge about science concepts and knowledge about the practice of science drawing. Conceptual knowledge refers to the science community’s currently accepted facts and ideas and the organized relationships among them, which explain science phenomena. Science practices refers to the ways conceptual
knowledge is acquired and communicated both within and outside the science community. Driver et al. (1994) argued that individuals will not independently discover the tools, concepts, and organizing ideas of science just through observations of the natural world. Science learning includes both ideas and practices. The construct of SK in this research, which is used to describe science understanding, has been referred to in several ways in education research literature, including science content knowledge and science matter knowledge (Van Driel et al., 2014; Diamond et al., 2014). In this research SK was used to convey a broader sense of both knowing science and doing science, versus terminology that might suggest just knowledge of science facts. Schwab (1978, as cited by Kind, 2014) categorized SK that teachers need to know as substantive versus syntactic. Substantive SK encompasses concepts currently accepted as facts and the ways they are connected together to explain phenomena. Syntactic SK encompasses the ways in which science knowledge is acquired and communicated.

Appleton (2003) found that limited SK, along with limited science PCK, influenced science teaching strategies of beginning elementary teachers, which included science avoidance. Appleton also found that the beginning teachers also relied on hands-on strategies with which they are familiar but not necessarily focused on student learning or well connected to science standards.

While teachers’ SK has been associated with the amount of science inclusion in the elementary classroom and its implementation (Appleton, 2003), there has been limited empirical data evaluating the association between elementary teachers’ SK and student learning outcomes. In a study by Buczynski and Hansen (2010), elementary teachers participated in a science inquiry-based PD in this study, which consisted of both a summer institute and sessions throughout the following school year. The summer institute focused solely on science content,
while the Saturday sessions during the school year included science content and pedagogy. For the content sessions on Saturdays, the teachers had higher post-test scores on content assessments developed specifically by session instructors. In addition, their students’ performance on the standardized science tests showed greater improvement compared to overall scores for their district. However, the student outcomes cannot be attributed solely to their teachers’ SK, since the PD included pedagogy sessions, which would influence their PCK.

Bleicher and Lindgren (2005) have argued that while PSTs’ SK is important for preparation of teachers during their elementary education programs, increased content courses are not an effective solution because they fail to also support the PSTs’ STEB and PCK. Appleton (2003) similarly discussed that PSTs should acquire SK in the context of building their PCK. One of the ways that beginning elementary teachers have been found to build their PCK in the field is through use of hands-on activities from their own educational experiences. Therefore, Appleton recommended that teacher education programs provide a cohesive set of activities that can be used to support elementary students’ science learning across science disciplines. PSTs would learn about the activities during methods courses in which they would be using them to build their own SK, while also building PCK.

Shulman (1987) is credited with the original framework for PCK, which is conceptualized to 1) include discrete categories of knowledge, 2) be a dynamic construct of teachers 3) be dependent on SK, and 4) involve transformation of other types of knowledge (Abell, 2008; Kind, 2009). Magnussen et al. (1999) expanded on Shulman’s original framework to expand transformed knowledge (Kind, 2009) into five subcomponents. The first subcomponent, orientation to teaching, is influential on the other four, which included knowledge of instructional strategies, knowledge of assessments, knowledge of student
understandings, and knowledge of science curriculum. The PCK subcomponent of instructional strategies is the focus of the learning outcomes in this study.

Based on results from the 2018 NSSME (Smith & Craven, 2018), in addition to lack of content competency, the teachers also do not feel well prepared to teach science based on their PCK. For the science teaching tasks included in the survey, the majority did not feel well prepared to carry out the tasks for which drawing could be incorporated as an instructional strategy. For example, for example only 16% of third to fifth grade teachers in self-contained classrooms felt very well prepared to develop students’ abilities to do science. For other tasks that could incorporate drawing in the classroom, such as using formative assessments to monitor learning, developing students’ conceptual understanding of science ideas, and basing instruction on students’ ideas, only 11 to 26% of third to fifth grade self-contained teachers felt very well prepared. Appleton (2003) found that beginning elementary teachers use a strategy of “what works” for science instruction in the classroom and often borrow from strategies for other content areas or hands-on activities from their own education experiences.

**Elementary Teachers’ Preparation for Science Instruction**

Teacher education programs are a critical time to support teachers’ preparation for including reform-based strategies like drawing-to-reason in the classroom (Kennedy, 1999). Practices incorporated into teacher education programs play a significant role in building PSTs’ affective characteristics, SK, and PCK. Kluth and Straut (2003) have noted the importance of teacher education programs explicitly modeling the instructional practices of collaboration in the courses for preservice teachers. Stofflet and Staddard (1994) stated that “if teachers are to use conceptual teaching methods in their own classrooms, they need to learn content and pedagogy
through the same conceptually based methods reformers are advocating be used with grade school students.”

Teachers’ affective characteristics are shaped by multiple factors over the course of teachers’ careers, and teacher education programs play a significant role in shaping PSTs’ affective characteristics towards science and teaching as they embark on their careers. Science methods courses during elementary teacher education programs have been shown to influence PSTs’ affective characteristics, SK and PCK (Avraamidou & Zembal-Saul, 2005; McDonald et al., 2021). While elementary PSTs’ STEB has been shown to be influenced by participation in science methods courses during their teacher education programs, but not by science content courses (Morrell & Carroll, 2003).

Education research supports the importance of addressing PSTs’ affective characteristics while simultaneously building their SK and PCK during teacher education (Abell, 2008; Johnston & Ahtee, 2006; McDermott et al., 2006). Johnston and Ahtee (2006) researched the relationship among PSTs’ attitudes, SK, and PCK during a methods course that included physics-focused activities. Their study included Finnish and English primary PSTs, who were early in their respective education programs, and enrolled in a science methods course. These two different populations of PSTs were selected because of differences in their teacher preparation programs. Finland’s elementary teacher education in science places more emphasis on teachers’ attitudes and PCK versus building SK. However, in England there is an emphasis on building SK, and their instruction is more teacher centered. The study’s research questions addressed attitude, SK and PCK related to physics.

PSTs’ attitudes towards physical science teaching were measured based on a semantic differential attitude questionnaire, which contained bipolar adjective pairs to reflect positive
versus negative feelings towards ideas or activities. For comparison, Johnston and Ahtee (2006) also used the semantic attitude questionnaire to measure attitudes towards teaching their first language, mathematics, and science in general. For measuring the students’ SK, the teachers wrote predictions and explanations for a phenomenon-based activity that explored the concept of air as matter. This activity also was used as the basis for measuring the PSTs’ PCK by asking their ideas about students’ alternate conceptions and instructional strategies to address them.

The results from the attitude questionnaire indicated that in both Finnish and English preservice teachers, attitudes towards teaching different subjects were most negative for physics, with Finnish participants being more negative than their English counterparts. Attitudes were more positive for teaching science in general, mathematics and their first language. Responses for different bipolar adjectives were grouped into four attitudinal categories attributed to perceived difficulty of the subject, interest in the subject, nature of the subject, and value of the subject. For Finnish PSTs, their attitudinal responses were the most negative for categories attributed to perceived difficulty and nature of physics. English PSTs were less negative towards physics based on perceived difficulty compared to Finnish PSTs, as well as reporting positive attitudes based on the category of adjectives attributed to the perceived nature of physics.

Johnston and Ahtee (2006) attributed the differences between the two groups of PSTs to differences in their respective educational systems. In Finland, the primary schools focus predominately on biology and geography, versus English primary schools, which focus on physics and chemistry in addition to biology. The authors pointed out that more negative attitudes towards physics compared to biology may reflect the perception of physics as “too difficult, too mathematical, too abstract” (p. 504).
For analysis of the PSTs’ SK, more English PSTs made accurate predictions for what would happen with the demonstrated phenomenon, which used two balloons to demonstrate that air has mass. However, the percentage of PSTs who provided accurate explanations for the why the phenomenon occurs was approximately the same. In addition, alternate concepts were similar between the two groups of PSTs. The researchers also noted the similar use of inexact terminology and reliance on everyday experiences to explain the phenomenon.

For PCK, PSTs’ responses for what elementary students might struggle with regarding the topic were grouped into five categories termed Understanding/Believing/Accepting, Misconceptions, Vocabulary, Other, and None. Most responses for both groups of PSTs were classified as Understanding/Believing/Accepting. The PSTS thought students would find the concept of air having mass abstract since it cannot be seen or felt. The researchers attributed the PSTs’ responses to their focus on SK. The other question assessing their PCK focused on PSTs’ perceived needs for teaching the activity. Both the Finnish and English PSTs focused on their need for more SK to accurately demonstrate and explain it to their students. The researchers classified most responses as teacher-centered instructional concerns, while only 10% of all the PSTs focused on elementary student thinking.

Johnston and Ahtee (2006) concluded that PSTs will need support that is both meaningful and accessible during their teacher education program to build SK and PCK to instruct physical science in the classroom. They recommended teacher educator programs address PSTs’ attitudes towards physical science and incorporate practices in science methods courses that focus on PSTs’ prior knowledge and building SK through conceptual change. Building SK was recommended to precede development of PCK, since limited SK can be a barrier for teachers to focus on student understanding.
There are limited studies of PSTs’ learning outcomes from inclusion of drawing during science methods courses. Laaman and Jay (2015) explored how the use of drawing during a science content course for PSTs supported their SK. They did not specify the science disciplinary focus of the course in the article. During the course, one section had an out-of-class assignment to create a definition page for a list of terms related to concepts covered during in-class activities. The second group of PSTs were instructed explicitly to include drawings as part of their definitions. PSTs who drew definitions scored higher on a multiple-choice test on the defined concepts at the end of the lesson series. However, it was not clear if outcomes were specific for drawing-to-reason. Nelson and Davis (2012) included both PST-generated drawing-to-reason about evaporation and condensation, as well as guidance and practice evaluating elementary students drawn models. The investigators found that the PSTs gained both STEB and PCK regarding use of a set of criteria to assess students’ drawings. While they most frequently used aesthetic criteria when evaluating the students’ drawings, they also incorporated other important criteria such as sense-making to discuss the explanatory power of the students’ drawings.

**Conceptual Framework for Study**

Based on literature support for the learning benefits of drawing in science and the need to support teachers’ incorporation of and instructional practices with drawing, the purpose of this study was to explore the benefits of including explicit instruction on drawing-to-reason during a science methods class for elementary PSTs to prepare them for teaching science. While there are multiple purposes for the instructional use of drawing in the elementary classroom (Ainsworth et al., 2011), this study focused on explicit instruction of drawing-to-reason, because it serves as a form of science modeling to build conceptual knowledge. The *Framework for K-12 Science Education* (NRC, 2012) and *Next Generation Science Standards* (NRC, 2013) have emphasized
the need for K-12 students to engage in science and engineering practices like modeling as they build SK. Therefore, preparing PSTs to use drawing-to-reason as a science instructional strategy may support its incorporation in their future classrooms. In addition, because physical science is a content area in which most teachers express feeling least prepared (Yilmaz-Tuzun, 2008), the study focused on force-related phenomena during lessons with explicit instruction on drawing-to-reason.

The conceptual framework for this study (Figure 2.1) was grounded by Vygotsky’s theory of sociocultural constructivism (Wertsch, 1985; 1991) and incorporated the instructional interventions from Quillin and Thomas (2015) to explore teacher outcomes based on Desimone’s (2009) path model.

Figure 2.1

*Conceptual Framework for Study*
The following sections provide additional details regarding the theoretical perspective for
the framework, drawing-to-reason instructional interventions, PSTs’ learning outcomes
regarding affective characteristics, SK and PCK, and the research questions guiding the study.

**Theoretical Perspectives**

In their literature review of research on the use of drawing for learning in science,
technology, engineering, and mathematics content, Wu and Rao (2019) categorized the
theoretical framing of research studies as either cognitivist or sociocultural based on the research
purposes of study. Studies with cognitivist framing were concerned with exploring why the
process of drawing supports learning, for example generative learning (van Meter, 2001), self-
regulation (Hellenbrand et al., 2019), mental model integration (Williams et al., 2019), and
spatial cognition (Cooper et al., 2017). Studies with sociocultural framing have multiple goals
and are focused on both the engagement with drawing as well as the learning outcomes from
drawing. For example, the use of drawing as a tool for effective science communication
(Williams et al., 2019) and enculturation into science by engaging with the disciplinary practices
of drawing (Prain & Tytler, 2012).

Quillin and Thomas (2015) based their instructional framework for drawing-to-reason, on
the theory of cognitive capacity (Sweller, 1988; De Jong 2010) because they were interested in
explaining why the interventions included instructional framework could support biology
students becoming more expert users of drawing-to-reason based on modeling aspects. Based on
the theory of cognitive capacity, Quillin and Thomas proposed that explicit instruction would
minimize other learning distractors, because the students would focus only on the drawing
instruction. The affective interventions would motivate the students to commit significant
cognitive capacity for drawing-to-reason, the visual literacy interventions would help minimize
cognitive capacity focused on how to draw and allow them to think and incorporate more science concepts and principles in their drawings, and the modeling practice would lead them to more spontaneously use drawing-to-reason to problem-solve.

However, the purpose of this research was to explore how PSTs engaged with drawing-to-reason during their science methods course with explicit drawing instruction, as well as their learning outcomes from engagement with drawing-to-reason. Therefore, the conceptual framework (Figure 2.1) was grounded by Vygotsky’s theory of sociocultural constructivism (Wertsch, 1985; 1991), which has been posited by Eun (2008) as relevant for understanding what teachers learn from professional development and by van Huizin et al. (2005) for teacher education programs, particularly because of Vygotsky’s emphasis on the interrelationship of affective, cognitive, and behavioral learning.

One key construct from Vygotsky’s socio-cultural theory relevant to this study is the Zone of Proximal Development (ZPD). Of the different forms for how Vygotsky’s ZPD has been applied (Eun, 2019), the concept of ZPD as a space between active information versus understood information was relevant for considering the role of drawing-to-reason in an elementary PSTs’ preparation for teaching science. Vygotsky’s ZPD has both a spatial and temporal dimension (Eun 2019). The spatial dimension is the gap between an individual’s current versus future understanding, which is not static, but rather dynamic over time as the individual builds knowledge. In this study, active information was PSTs’ prior knowledge about physical science, drawing, or science teaching from their previous educational experiences. The understood information was the knowledge that is gained throughout the science methods course with the guidance of a more knowledgeable peer, who for this study was the course instructor.
Another relevant Vygotskian construct for this study was the idea of mediational tools (Wertsch, 1985; 1991). Vygotsky’s posited that humans use both physical and symbolic tools to understand and interact with the world (Shabani, 2016). In this study, the PSTs’ drawings were physical mediational tools because they were used by the PSTs to build conceptual knowledge about the force-related phenomena, to develop knowledge and skills for drawing-to-reason in science, and to learn how to incorporate drawing-to-reason in their own science instruction.

**Instructional Interventions**

According to Quillin and Thomas’s (2015) framework, instructional interventions that are important for supporting drawing-to-reason are categorized as affective, visual literacy, and modeling (Figure 2.2). They theoretically grounded their framework based on cognitive capacity (Sweller, 1988; de Jong, 2010). Therefore, their framework conceptualized the interventions as a sequence of instructions starting with affective interventions to motivate the students and that the subsequent steps of visually literacy and modeling would recursively feedback on other interventions because of changes in cognitive capacity.

However, for this study, the categories were not conceptualized as ordered steps, but rather holistically as collection of interventions that were implemented interactively to support the PSTs’ engagement with drawing-to-reason during the lessons. What was considered important was the inclusion of all the distinct types of interventions during the lessons, but not necessarily, the sequence in which they were implemented. This reflects the sociocultural framing for this study in which learning is an interrelationship of affect, cognition, and behavior (DiPardo & Potter, 2003).
**Figure 2.2**

*Categories of Instructional Interventions*

**PSTs’ Learning Outcomes**

Relevant learning outcomes for PSTs from the incorporation of drawing instruction in a science methods course was based on Desimone’s (2009) path model. According to her theory of action, measures for teachers’ attitudes, beliefs, and knowledge can be used to evaluate the effectiveness of interventions in professional development. The relevance of these as teacher learning outcomes reflects Korthagen’s (2017) onion model that teachers’ learning is multi-dimensional and includes cognitive, emotional, and behavioral factors. While the design of this study was not causal research, Desimone’s pathway was used to identify teacher outcomes that may lead to improved classroom instruction and student learning. Therefore, the learning outcomes of interest after drawing instruction were PSTs’ affective characteristics, SK and PCK.

As described previously in this chapter, *affective characteristics* are directed towards an idea, object, or activity (Anderson & Bourke, 2000). This study was interested in understanding PSTs’ affective characteristics towards drawing, physical science, and teaching after explicit instruction on drawing-to-reason. The specific affective characteristics towards drawing included
PSTs’ attitude, interest, self-efficacy, and value. In addition, their affective characteristics towards physical science were explored as a possible learning outcome, because the PSTs’ drawings focused on reasoning about force-related phenomena. Finally, based on education research supporting the role of science methods courses in shaping PSTs’ attitudes and beliefs (Keys & Bryan, 2001), the specific affective characteristics towards teaching included PSTs’ attitude towards science teaching and their STEB.

Assessment of affective characteristics requires specification of both a conceptual definition in abstract terms, as well as an operationalized definition specific to a study (Anderson & Bourke, 2000). The definitions that were the basis for assessment of affective characteristics in this study are listed in Table 2.3.

Learning outcomes regarding SK were categorized as concept knowledge and knowledge of science drawing (Table 2.3). Based on the sociocultural framing for this study, the PSTs had prior knowledge about force and motion, which they would build on while engaging with drawing-to-reason about the force-related phenomena incorporated into class lessons during the science methods course. The PSTs’ drawings were considered external representations for their understanding of the phenomena, which would evolve to be more consistent with canonical explanations for the phenomena as they engaged with the course content and the practice of drawing-to-reason. The PSTs also were considered to have prior knowledge with science drawing prior to the science methods course, but over the series of lessons with explicit instruction on drawing-to-reason, they would develop more expert use of drawing based on the model use aspects outlined by Quillin and Thomas (2015). As described previously in this chapter, Quillin and Thomas (2015) outlined seven distinct aspects based on literature. However, as described in Chapter Three, during the process of structuring of the category matrix for
deductive content analysis of the PSTs’ drawings, the aspects were narrowed to three distinct categories, including model relationships, purpose and salient features, and metacognition.

The final learning outcome regarding PCK focused on its subcomponent of teachers’ knowledge of instructional strategies in science (Magnussen et al., 1999), which in this study was PSTs’ knowledge of the instructional strategy of drawing-to-reason in science. PCK learning outcomes were operationalized (Table 2.3) based on PSTs’ inclusion and instruction of drawing during science lessons for their semester field experiences in elementary classrooms. Their drawing instruction practices were evaluated based on how they would support elementary students’ use of drawing according to the model use aspects, which were used to assess the PSTs’ SK learning outcomes.

Research Questions

Based on the described conceptual framework, the following three research questions were used to explore PSTs’ learning outcomes regarding affective characteristics, SK and PCK in a science methods course that incorporated explicit instruction on drawing-to-reason:

1. How do PSTs’ self-reported affective characteristics towards drawing, physical science, and science teaching change from the beginning to the end of the science methods course?

2. How do PSTs’ ideas and drawings about force-related phenomena evolve over a series of lessons that include explicit instruction on drawing-to-reason?

3. In what ways do PSTs incorporate drawing as an instructional strategy in their science lesson plans for their field experiences after explicit instruction on drawing-to-reason?
### Table 2.3

**Conceptual and Operational Definitions for Learning Outcomes**

<table>
<thead>
<tr>
<th>Learning Outcome</th>
<th>Conceptual Definition</th>
<th>Operational Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Affective Characteristics</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Attitude</strong></td>
<td>Latent construct with affective, cognitive, and behavior components defined as “tendency to respond with some degree of favorableness or unfavorableness” (Fishbein and Ajzen, 2009, p. 76).</td>
<td>PSTs’ like or dislike of science drawing, physical science, or science teaching (in general and/or physical science specifically)</td>
</tr>
<tr>
<td><strong>Interest</strong></td>
<td>Latent construct with affective, cognitive, and behavior components that reflects an individual’s disposition to learn more about or engage with an idea, object, or activity.</td>
<td>PSTs’ disposition to want to learn more about or to engage with drawing-to-reason or physical science for their own learning or for teaching</td>
</tr>
<tr>
<td><strong>Self-efficacy</strong></td>
<td>Latent construct with affective, cognitive, and behavior components defined as an individual’s belief in their ability to effectively engage with activities such as teaching or learning.</td>
<td>PSTs’ beliefs about their ability to effectively engage with drawing or teach science</td>
</tr>
<tr>
<td><strong>Value</strong></td>
<td>Latent construct with affective, cognitive, and behavior components defined as an individual’s evaluation of the importance or acceptability of a targeted idea, object, or activity based on cultural norms or personal beliefs</td>
<td>PSTs’ evaluation of the importance or utility of drawing-to-reason as a strategy for elementary student learning</td>
</tr>
</tbody>
</table>
### Table 2.3 (continued)

<table>
<thead>
<tr>
<th>Learning Outcome</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Conceptual</strong></td>
<td><strong>Operational</strong></td>
</tr>
<tr>
<td><strong>Science knowledge (SK)</strong></td>
<td></td>
</tr>
<tr>
<td>Concepts</td>
<td>Ideas about structures, relationships and processes that explain science phenomena</td>
</tr>
<tr>
<td>Science Drawing</td>
<td>Authentic science practice of drawing to build knowledge and make meaning about phenomena</td>
</tr>
<tr>
<td><strong>Pedagogical content knowledge (PCK)</strong></td>
<td></td>
</tr>
<tr>
<td>Knowledge of instructional strategies</td>
<td>One of the components of teachers’ specialized knowledge for teaching that includes their understanding of effective strategies that support student learning</td>
</tr>
</tbody>
</table>
CHAPTER 3

METHODOLOGY

The purpose of this study was to explore four elementary PSTs’ learning outcomes based on affective characteristics, SK, and PCK during a science methods course that incorporated explicit instruction on drawing-to-reason about force-related phenomena. In this research, drawing-to-reason has been defined as the creation, evaluation, and revision of hand-sketched drawings to represent an individual’s own ideas about science phenomena, and therefore, has been considered a form of modeling. The explicit instruction on drawing-to-reason was guided by Quillin and Thomas’s (2015) instructional intervention framework that targets affect, visual literacy, and modeling. A mixed methods study design was used for this intervention study in which both quantitative and qualitative data were collected and analyzed concurrently to explore the following sub-questions:

1. How do PSTs’ self-reported affective characteristics towards drawing, physical science, and science teaching change from the beginning to the end of the science methods course with explicit instruction on drawing-to-reason?
2. How do PSTs’ drawings and ideas about force-related phenomena evolve over a series of lessons that include explicit instruction on drawing-to-reason?
3. In what ways do PSTs incorporate drawing as an instructional strategy in their science lessons for field experiences after explicit instruction on drawing-to-reason?

This chapter will provide justification and rationale for the use of mixed methods for addressing the central question via the three sub-questions, establish researcher positionality, including epistemological and ontological assumptions in relation to the study, outline the proposed
methods of the research design including the study context, study participants, data collection, and data analysis, and address issues of trustworthiness.

**Justification and Rationale for Research Methodology**

A typology-based approach was used to select the mixed methods design for this research (Creswell & Plano Clark, 2018). Based on Creswell and Plano Clark’s (2018) most recent typology, a convergent design was used in which the qualitative and quantitative data collection and analysis occurred simultaneously, and the results from both strands were converged together to build an understanding about the case. While there were two strands of primary data in the convergent mixed methods design for this study, more emphasis was placed on the qualitative strand than quantitative strand in the interpretation of the data.

The mixed methods study was conducted within the framework of a single case study with embedded units of analysis (Figure 3.1). For the study, the overall case was an elementary teacher education science methods course that was bounded by its focus on teaching science in third to fifth grade and the inclusion of explicit instruction on drawing-to-reason about force-related phenomena during a series of 5 weekly lessons as part of the 14-week semester. The researcher served as the instructor of record for all course activities, including the series of lessons on explicit instruction on drawing-to-reason for this study. The embedded subunits in the single case were individual PSTs, who were junior undergraduate students in their second semester of a STEM-focused elementary education program. The four PSTs had initial differences in their self-reported affective characteristics towards drawing, physical science and science teaching, force-related conceptual knowledge, and prior educational experiences with drawing.
Figure 3.1

*Mixed Methods Design*

![Diagram of Mixed Methods Design]

Note: Convergent mixed methods design with parallel collection of qualitative (QUAL) and quantitative (quan) data, with emphasis on the QUAL data. The mixed methods design was implemented within the framework of a single case study with embedded units of analysis (Yin, 2018).

As outlined in Chapter Two, the research questions, data collection, analysis, and interpretation were guided by a socio-cultural theoretical perspective (Wertsch, 1985; 1991) in which collective learning and enculturation into the practice of teaching occurs through PSTs’ engagement with authentic activities that are guided by a more knowledgeable facilitator. The use of mixed methods for the research was chosen primarily to triangulate findings from primary
sources of evidence collected longitudinally during a science methods course, and secondarily because a convergent data analysis helped elaborate, enhance, and illustrate findings (Bryman, 2006).

**Researcher Positionality**

Positionality addresses questions of the relationship between the researcher and the study, including how their values and beliefs influenced its design, implementation, interaction with participants, and research findings. The researchers’ system of beliefs has been referred to as their worldview (Creswell & Plano-Clark, 2018) or the research paradigm (Scotland, 2012; Guba & Lincoln, 1994), and it is based upon philosophical assumptions about the source of knowledge and the process of knowing. This section on researcher positionality will use the term worldview for the values and system of beliefs, including the ontological, epistemological, and axiological assumptions that were the philosophical underpinnings of this study.

A researcher’s worldview guides the selection of a study’s theoretical lens, methodological approach, and research methods (Crotty, 1998). Creswell and Plano-Clark (2018) discuss the importance for graduate students, in particular, to reflect on and articulate their worldview as they plan and conduct their dissertation research. Clarity about one’s values and philosophical assumptions enables the researcher to engage in reflexivity during data analysis and interpretation (Wilson et al., 2022), which can serve as one measure of trustworthiness for the research findings. Therefore, this section provides a summary of this researcher’s worldview about knowledge in relation to this research study, including her beliefs about drawing and the relationship of her philosophical assumptions to the outlined research methodology, methods, and findings.
In a traditional philosophy of knowledge approach, worldviews are defined based on ontological, epistemological, and axiological assumptions. Simply stated, ontological assumptions deal with what there is to know in the natural or the social world. Epistemological assumptions address the question of how knowledge is understood. It includes questions regarding the nature of knowledge and the process of making sense and building meaning about the world, such as how knowledge is acquired, how it is communicated to others, what is believed to be true, and what is the basis for the truth (Bryman, 2008). Axiological assumptions deal with values and their relationship to research findings.

Ontological, epistemological, and axiological assumptions have been defined on a continuum between the extreme positions of positivism or postpositivist versus constructivism (Creswell & Plano-Clark, 2018). Postpositivist ontological stances are realist and assume an independent, objective reality that can be discovered, while constructivist stances are relativist and assume that individuals create meaning, which is dependent on social context and can differ among individuals because it is mediated by their senses (Scotland, 2012). Post-postivist epistemological stances believe in an objective truth that can be discovered through empirical measures, while constructivist believe there are multiple, independent, subjective truths which an individual builds based on their experiences. Axiological assumptions that are postpositivist recognize research as value-driven and incorporate control methods so that findings are considered more value-neutral. In postpositivist positions, the purpose of research is to describe, explain, relate, and intervene. In contrast, while constructivists also recognize the influence of value on research, instead of controlling it, they incorporate and recognize it as important for interpretation and understanding of a studied social phenomenon (Shan, 2021).
In both post-positivist and constructivist worldviews, ontological assumptions about whether a reality exists independently or is mediated by an individual’s mind are the central drivers for the methodology, and therefore, constrain the epistemological assumptions and in turn the axiological assumptions and methods used for inquiry (Shan, 2021). An alternative to these ontologically oriented worldviews is pragmatism, which is axiologically oriented, and therefore, driven by problem solving and not constrained by the notions of incommensurability of quantitative and qualitative methods or a binary stance of post-positivism versus constructivism (Morgan, 2014). Pragmatism allows for an independent physical world about which knowledge can be socially constructed and mediated by individuals so that there is not just one single, simple reality. It recognizes that what exists in the physical world constrains our experiences in it, but our interpretation of the world is also limited by our experiences.

In addition, pragmatism recognizes that research is linked to values. Dewey, one of the founders of pragmatism, had a model of experience in which reflection on one’s beliefs guided their actions, while reflection on one’s actions modified or reinforced their beliefs (Morgan, 2014). Therefore, pragmatism allows for research methods that seek to both control the effect of value, as well as incorporate it during the inquiry, analysis, and interpretation process.

The philosophical assumptions underpinning this dissertation research were based on a pragmatic worldview to privilege an axiological position that allows for both quantitative and qualitative methods to explore the research questions based on decisions of how to build an understanding about PSTs’ learning outcomes from explicit instruction on drawing-to-reason. This pragmatic position for the study reflects the researcher’s prior background as an engineer and scientist, which prioritized quantitative methodologies to inquire about what there is to know and build evidence to explain, predict or describe phenomena, and her current research pursuits
as an educator, who has come to recognize the value of qualitative research to interpret and understand phenomena.

Regarding the role of value in research, this researcher recognizes that the focus of the dissertation study itself was influenced by her own values, and not solely by a knowledge gap or an identified problem based on an objective review of the literature. While Chapter Two did provide literature background to support the merits of research on drawing-to-reason with elementary preservice teachers, this researcher’s interest in the topic also was informed by her prior educational background and professional experience as an engineer and scientist. In her chemical engineering, she was educated on how to create engineering sketches of objects in her first year and throughout all her courses would generate drawings as part of the problem-solving process. Her research focus as a toxicologist involved computational modeling to help explain and predict the amount of environmental chemicals and pharmaceuticals that enter the body of humans or animals, where they are distributed, how much is present in tissues, and how and when they are eliminated from the body. While her published research involved computational models, drawing was a practice she engaged with throughout her career, particularly for the purposes of reasoning through ideas, both individually in her science notebooks but also on group settings with other scientists in which shared ideas were compared and contrasted with drawings on white boards. Therefore, she values the significant role of drawing as a form of modeling because of personal experience and knowledge that it is an authentic practice that builds both personal and shared science knowledge and seeks to promote it as a practice in elementary science education.

The value placed on drawing as an authentic science practice for building knowledge also reflects the researchers’ epistemological belief that individual meaning is constructed through
lived experiences during interactions with others in a social context. As discussed in Chapter Two, Vygotsky’s zone of proximal development provided the theoretical underpinnings for the conceptual framework with instructional interventions and PST learning outcomes in this study. During the science methods course, PSTs were socially constructing their affective characteristics, SK, and PCK needed to teach science in the upper elementary grades. They did not discover the SK and PCK, nor did the instructor transmit the knowledge, but rather the PSTs constructed their knowledge over time with guidance by the instructor as the more knowledgeable peer. Each PSTs’ prior knowledge and experiences mediated their interactions within the course and their learning from the experience. However, their learning was constrained by what the instructor valued as important for the PSTs to experience as they built their knowledge for teaching.

The pragmatic worldview guided the data collection and analysis used to build an understanding of what the PSTs learned during the course. In the study, learning outcomes were based on constructs (Table 2.3) with literature-supported conceptual definitions of affective characteristics and aspects of model use, and canonical explanations for science phenomena. These constructs were operationalized based on qualitative measures, as well as quantitative measures when literature resources were available. For example, quantitative methods, such as survey instruments and knowledge assessments, were used as measures for affective characteristics and SK. Qualitative methods, such as semi-structured interviews and PSTs’ coursework artefacts, also were used to explore learning outcomes regarding affective characteristics, SK, and PCK, but the content analysis was deductive based on a priori defined codes. The overall understanding of the science methods course was interpreted within the structure of a case study with embedded subunits for the consenting PSTs. This researcher
believed that the triangulation of the qualitative with quantitative measures was important for building thick, rich descriptions for the PSTs’ learning outcomes that were situated within literature-based definitions for affective characteristics, SK, and PCK. These synthesized descriptions for the PSTs were the basis for an overall understanding of the science methods course with explicit instruction on drawing-to-reason.

**Institutions Review Board and Data Storage**

A study proposal was designed and approved by the NC State Institutional Review Board for this research. The approved proposal included participant recruitment, a consent process for both the study and for broad consent for future unspecified use of data artifacts, research methods including all survey instruments, assessment tools, and interview protocols, data collection and storage procedures. The details regarding participants, consent, research methods, data collection, and data analysis will be discussed in more detail in the remainder of the chapter. Consent acquisition and data storage was conducted in accordance with the approved IRB protocol.

**Participants**

Convenience sampling was used for this study. Participants were recruited from the junior cohort of undergraduate PSTs in the College of Education program at NC State University and were enrolled in the researcher’s section of ELM 420 Teaching Science in the Intermediate Grades during the Spring 2022 semester. During a class session, the researcher presented an overview of the study based on an IRB-approved script. Consent forms were distributed for the PSTs to review after class, and they were instructed to sign and return if they would like to voluntarily consent. The researcher also followed up with an IRB-approved email and electronic forms after class. For PSTs who did not return consent forms prior to the end of the semester,
one last IRB-approved email was distributed to request consent. Because data artifacts for the study include PST coursework, the PSTs were assured that participation or lack thereof did not influence their course grade.

All PSTs in the course participated in the learning activities and completed all coursework, but course artifacts for data analysis were only used from the consenting PSTs. From the PSTs who consented, four were included as part of the case study based on their attendance at all five lessons that were part of the explicit instruction on drawing to reason, submission of all coursework needed for the data analysis, and use of pencil and paper for creating sketches for their explanations. Other consenting PSTs, who were not included for this research analysis, were either in a subgroup that had similar lessons to build SK but without the drawing-to-reason component or were absent, used different drawing medium, or were missing coursework needed for the data analysis.

In addition, PSTs’ knowledge that the research study focused on drawing as an instructional strategy could bias the outcome, since it could affect how PSTs engaged with the practice and their attitudes both prior to and after the lessons in which it was incorporated. Therefore, the overview for the research and the consent forms only included that the research was conducting an intervention study with generic instructional practices to learn about effective science instruction during teacher education programs. Because this falls under IRB’s definition of deceptive research, the researcher shared the actual focus of the study after the semi-structured interviews were completed.

**Case Study Context**

This single case study with embedded units of analysis was bounded by a science methods course for grades three to five, which included explicit instruction on drawing-to-reason
as part of the course content. The course, ELM 420 Teaching Science in the Intermediate Grades, was a required course for the junior PSTs during their first year in the STEM-focused elementary teacher education program. The researcher served as the instructor of record for the course section in which participants for this study were recruited. An overview of the researcher’s section of the science methods course during Spring 2022 is described below, including the overall objectives, course length, class structure, and course content, including the lessons with explicit instruction on drawing-to-reason.

**Science Methods Course Description**

ELM 420 Teaching Science in the Intermediate Grades was a 14-week course that included 12 weeks of class meetings with the instructor and 2 weeks in which the PSTs were in their assigned elementary classrooms for field experiences during the entire week. Their field experiences for the semester also included half days in their assigned schools, but they only engaged with science instruction during the two full weeks of field experience. The researcher’s section of ELM 420 had a total of 23 PSTs. The class was divided into two subgroups for the semester, so that the 3-h class meetings each week could be divided between asynchronous activities and in-person activities. This allowed for lower student-to-instructor ratios to facilitate more active engagement during the in-person activities. The order of asynchronous and in-person activities alternated each week between the two subgroups.

The purpose of ELM 420 is to prepare PSTs to facilitate science instruction in 3rd to 5th grade classrooms. The researcher’s section of ELM 420 in addition to drawing-to-reason included content and activities that covered formative assessment, science standards, digital technologies for science instruction, productive questioning, student-centered investigations, discrepant events, trade books, lesson planning based on 3E learning cycle models (Marek,
2008), and field trip planning. The included content and activities were based on the following overall course objectives:

1. Describe and apply science standards (state and national) for grades 3 to 5.
2. Demonstrate the ability to plan science lessons and instruction collaboratively with teaching peers.
3. Locate, evaluate, and utilize science education resources such as trade books, research reports, digital media, and community resources in the teaching of science in the upper elementary grades.
4. Demonstrate knowledge of and proficiency with several practices used in inquiry-based science lessons to activate students’ prior knowledge, elicit student thinking, and build science conceptual knowledge and vocabulary.
5. Demonstrate and apply knowledge of culturally responsive science teaching in the upper elementary grades.

The required textbook for the course was *Primary science: Taking the Plunge* (Harlen, 2001) and weekly readings were used as the basis for each week’s activities. Table 3.1 provides an overview of the content and activities over the course of the semester, including the series of five lessons with explicit instructions on drawing-to-reason.
Table 3.1

**ELM 420 Weekly Meeting Description**

<table>
<thead>
<tr>
<th>Week</th>
<th>Topic</th>
<th>Weekly Reading from Harlen (2001)</th>
<th>Weekly Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>In-person</td>
</tr>
</tbody>
</table>
| 1    | Course Overview and Introduction | - Climer Cards (Climer, 2023) relationship-building activity  
- Syllabus overview  
- Draw-a-Science Teacher (Thomas et al., 2001) activity and discussion | - What Makes a Scientist? (n.d.) adapted to a NearPod unit (T. Leavens, personal communication, 2022) |
- ATLAST Force and Motion multiple choice assessment (Horizons Research Inc., 2011; Appendix A)  
- T-STEM survey instrument (Appendix B)  
- Reading discussion with TQE format (Gonzales, 2018) | - Reading response activity  
- Paige Keeley nature of science probe (Keeley, 2010)  
- “The Great Fossil Find” (Randak & Kimmel, 2022) adapted to a NearPod unit (T. Leavens, personal communication, 2022) |
| 3    | How Can We Elicit and Assess Students' Thinking? | Chapter Five: “Taking Student's Ideas Seriously”  
Chapter Nine: “Assessment for Learning”  
- SDA instrument (Appendix C)  
- Overview for KLEWS charts (Kastel & Renfrew, 2017)  
- Paige Keeley assessment probes overview (Keeley, 2018) and small group activity with examples | - Select probe from compiled resources (T.Leavens, personal communication, 2022) for 1st field experience lesson  
- Start draft of 3E lesson plan |
### Table 3.1 (continued)

|------|-------|-----------------------------------|-------------------|--------------|
| 4*   | How Can We Support Student Communication and Discourse in the Classroom? | Chapter Two: “Bringing Children & Science Together”  
Chapter Eight: “Helping Children to Communicate” | - Reading recall discussion activity-“Two Truths and a Lie” (Rhodes, 2022)  
- Classroom communication practices including talk moves, notebooks, and drawings  
- Cartesian diver demonstration and discussion  
- Lesson planning guided work session | - Peer review lesson plans |
| 5    | Field Experience Week One | | | |
| 6*   | How Do We Create Interest with Phenomenon? | Chapter Three: “The Right Question at the Right Time”  
Chapter Four: "Helping Children Raise Questions-And Answering Them" | - Review drawing  
- Hands-on activity, observation, and discussion of water wrung out from washcloth on earth vs space.  
- Drawing-to-reason about water phenomenon | - Science standards activity  
- PlayPosit bulb on productive questioning (T. Leavens, personal communication, 2022)  
- Review discrepant event ideas for 2nd lesson |

*Indicates weeks during semester in which explicit instruction on drawing-to-reason was incorporated in the in-person activities
<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td></td>
<td><strong>How Can We Explore with Models and Representations?</strong></td>
<td>Chapter seven: “Helping Children to Observe”</td>
<td>- Explore concept of water molecules</td>
<td>- Online science simulations and labs</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Explore concept of polarity with magnet analogy</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>- Evaluate and revise drawings</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>- Exploration comparing concepts of adhesion and friction</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Evaluate and revise drawings</td>
<td></td>
</tr>
<tr>
<td>8*</td>
<td>How Can We Support Sense-making in the Classroom?</td>
<td></td>
<td>- Review phenomenon and concepts from weeks 4 to 8</td>
<td>Teaching observation videos in PlayPosit (T. Leavens, personal communication, 2022)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Finalize drawing of explanation for water phenomenon</td>
<td>- Argumentation Charts</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Use of discrepant events in NGSS storylines (NGSS, n.d.)</td>
<td>- PlayPosit on fishbowl discussions (T. Leavens, personal communication, 2022)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Guided work session for planning discrepant event lesson for field experience</td>
<td></td>
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</tbody>
</table>

*Indicates weeks during semester in which explicit instruction on drawing -to-reason was incorporated in the in-person activities.
Table 3.1 (continued)

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>How Do We Assess Student Learning?</td>
<td>Chapter Nine: “Assessing for Learning” (review)</td>
<td>- ATLAST Force and Motion multiple choice assessment (Horizons Research Inc., 2011; Appendix A)</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Peer teaching of discrepant event lesson for field experience</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Field Experience Week Two</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>How Do We Engage Children with Science with Picture Books?</td>
<td></td>
<td>- Field Trip Project overview</td>
<td>- Work on Field Trip Project</td>
</tr>
<tr>
<td>14</td>
<td>What Have We Learned This Semester?</td>
<td></td>
<td>- Steve Jenkins Author Day activity with NC State Media Education and Technology Research Center</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Revisit course KLEWS chart for summative assessment of learning outcomes for semester</td>
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<td></td>
<td></td>
<td></td>
<td>- T-STEM instrument (Appendix B)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- SDA instrument (Appendix C)</td>
<td></td>
</tr>
</tbody>
</table>

*Indicates weeks during semester in which explicit instruction on drawing -to-reason was incorporated in the in-person activities*
Semester Field Experiences

As discussed above, part of the PSTs required coursework for the semester included field experiences in elementary classrooms to observe mentor teachers facilitating instruction in all content areas, observe and engage in teacher planning and development meetings, develop relationships with elementary students in their assigned classrooms, and plan and facilitate lessons in all content areas. For the spring semester of the junior year, PSTs were assigned with partners to grades three to five in elementary schools in local, partner school districts. During the semester, the PSTs were required to be in the field for a half-day once per week for the 12 weeks in which they also had in-person class meetings for their methods courses. In addition, there were two weeks of the semester in which the PSTs were in the field for four full school days and did not have in-person class meetings for their methods courses. During those two weeks, which are referred to in this dissertation as the first and second field experience weeks, the PSTs were required to plan and facilitate a science lesson for a small group of students in their assigned classroom for each week.

Their lesson for the first field experience week focused on implementation of a Page Keeley formative assessment probe (Keeley, 2018). At the beginning of the spring semester, the science methods course instructor contacted the mentor teachers in the PSTs’ assigned classrooms to request guidance for the content focus of the probes. This information was shared with the PSTs prior to their planning. The PSTs also communicated with their mentor teachers after selecting a probe for their lesson to get approval and input on their plan. PSTs collaboratively planned their lessons with their fieldwork partners and received feedback from the science methods course instructor and their peers. Each PST independently facilitated the lessons in their field classrooms. The lessons were planned and implemented as a 3E learning
cycle (Marek, 2008), which structures the overall lesson into engagement, exploration and explanation stages with formative assessment occurring throughout the lesson. The 3E learning cycle is adapted from the 5E learning cycle (Bybee et al., 2006) and has been shown as effective for supporting academic achievement in the science classroom (Sam et al., 2018). The 3E cycle was well suited for the lesson based on the limited time the PSTs were allotted for facilitating the lesson in their field classrooms. After facilitating the lesson, PSTs were required to complete a reflection on practice (Clara, 2015) based on a template (T. Leavens, personal communication, 2022), which was adapted from a format with which the PSTs had used previously in their undergraduate coursework for ECI 201 Introduction to Technology for Educators (R. Davis, personal communication, 2018). Dr. Davis created guidelines and a reflection rubric based on O’Sullivan et al. (2010).

Their lesson for the second field experience week was based on implementing a discrepant event (González-Espada et al., 2010) of their choice to engage students and elicit their ideas about the phenomenon. They were encouraged to select a discrepant event that would either build on science concepts their mentor teachers had focused on in previous classroom lessons or would elicit students’ prior knowledge about science concepts the mentor teacher planned to include in future lessons. PSTs collaboratively planned their lessons based on the 3E learning cycle with their fieldwork partners and received feedback from the science methods course instructor and their peers. Prior to facilitating the lesson in the field, each PST practiced leading their lesson with a group of peers during an in-person class meeting. During the second week of field experience, the PSTs independently facilitated the lessons with elementary students from their assigned classrooms. After facilitating the lesson, PSTs were required to complete a reflection on practice, which included the PSTs’ ideas for a series of lessons that could be used to
help the students build knowledge to construct an explanation for their discrepant event. The series of lessons is based on NGSS storylines for the use of anchoring phenomena in science learning (NGSS, n.d.).

**Description of Lessons with Explicit Instruction on Drawing-to-Reason**

The five lessons from the course that included on explicit instruction of drawing to reason (Table 3.2) focused on intermolecular water forces and were based on a series of lessons, which were created and facilitated previously by the instructor with elementary students. The series of lessons included an introduction to drawing in elementary science, engagement activities with phenomena, exploration with hands-on activities to build knowledge of concepts needed for explanation of the phenomenon, and iterative modeling to create, evaluate and revise drawings. The sequence of the lessons mirrored Schwarz et al. (2009) sequencing of lessons for exploring learning progression with the science practice of modeling.

The series of lessons were based on the Next Generation Science Standards storyline format (NGSS, n.d.), which uses a phenomenon to engage students in a series of inquiry-based lessons to build conceptual knowledge for constructing an explanation. The phenomenon used for the series of lessons compared the observed behavior of water wrung from a washcloth on earth to water wrung from a washcloth by an astronaut on the International Space Station (Canadian Space Agency, 2013). In this dissertation, this phenomenon will be referred to as the water-force phenomenon in the text, tables, and figures. It was selected for the series of lessons with explicit instruction on drawing-to-reason because a) it had been used previously for science instruction by the researcher, b) the lesson content was novel and would provide an opportunity to build SK, and c) the lessons content would provide an opportunity to transfer prior knowledge about force-related concepts, such as frictional and gravitational force, relevant to the motion of
objects on a more macro scale (e.g. objects on an inclined plane) to objects on a micro scale (e.g. water molecules).

The concepts covered in the lessons were based on Harlen’s (2010) framework of a “Big Idea” tree (Figure 3.2) for facilitating meaning making and providing coherence among concepts. The “Big Idea” tree also connected well to the course textbook (Harlen, 2001). The concepts that were part of the overarching big ideas (Figure 3.2) provided an opportunity to cover other instructional strategies for teaching science from the textbook, such as the use of manipulatives, incorporation of multiple types of models, and productive questioning to elicit student ideas.

Figure 3.2

Big Idea Tree for Water Phenomenon

Note: This idea tree was created based on Harlen’s Big Ideas in Science tree (Harlen, 2010) to include the big science ideas and the related concepts that are needed to make meaning about why the observed behavior of liquid water being wrung from a washcloth will differ in space compared with on earth.
<table>
<thead>
<tr>
<th>Drawing-to-Reason Lesson Number</th>
<th>Course Week</th>
<th>Lesson Description</th>
</tr>
</thead>
</table>
| One                           | 4           | Introduction to Drawing-to-Reason as Instructional Strategy  
- PowerPoint presentation on drawing in science (T. Leavens, personal communication, 2022) connected to Chapter 8 “Helping Children Communicate” from *Primary Science: Taking the Plunge* (Harlen, 2001, pp. 100–118)  
- Video “The Powerful Effects of Drawing on Learning” (Edutopia, 2019)  
- Introduction of graphic symbols to use with elementary students (Figure 3.4)  
- Cartesian diver demonstration (Frier & Anderson, 1996)  
- PST-generated drawings to explain for Cartesian diver phenomenon with pencil and paper (loose leaf 11x 17 plain paper) |
| Two                           | 6           | Review of Drawing-to-Reason  
- Review of graphic symbols to use with elementary students (Figure 3.4)  
- Instructor-modeled drawing on whiteboard of an explanation for Cartesian diver with graphic symbols for whole class while PSTs replicated instructor’s drawing in their science notebooks (See Figure 3.5)  
**Introduction of Water-force Phenomenon for Drawing-to-Reason**  
- Hands-on exploration, observations, and discussion about soaking washcloth in water and wringing the water out into a basin  
- Observation and discussion of video “Wringing out Water on the ISS—for Science!” (Canadian Space Agency, 2013), which was clipped in PlayPosit to exclude the explanation at the end of the video.  
- PST-generated initial drawings of explanations for the observed differences in water being wrung from a washcloth on earth vs in space pencil and paper (loose leaf 11x 17 plain paper and pencils) |
<table>
<thead>
<tr>
<th>Drawing-to-Reason Lesson Number</th>
<th>Course Week</th>
<th>Lesson Description</th>
</tr>
</thead>
</table>
| Three                         | 7           | Activities targeting concepts in Big Ideas #1 and #2 (Figure 3.2)  
- Discussion on PSTs’ prior knowledge about water and its physical and chemical properties  
- Instructor demonstration on whiteboard of different drawing representations of water, including text, symbolic form, labeled particle, and 2D stick and ball drawing (Explicit instruction on representational translations in drawings)  
- Hands-on activity to construct 3D model water molecules with toothpicks and gumdrops  
- Discrepant event demonstration of bending water stream with electrostatically charged balloon (Vanstone, 2022)  
- Discrepant event demonstration of rolling soda cans with electrostatically charged balloon (Vanstone, 2022)  
- Discussion of electrostatic charge  
- Discussion water molecule polarity  
- Instructor demonstration on whiteboard of different representational drawings of water molecule as a charged molecule  
- Hands-on exploration and discussion of polarity with magnets  
- Hands-on exploration with magnetized physical models of water molecules (3D Molecular Designs, n.d.)  
- Independent PST evaluation and revision of drawings from lesson two to include new ideas based on lesson content and feedback provided by instructor on initial drawing |
<table>
<thead>
<tr>
<th>Drawing-to-Reason Lesson Number</th>
<th>Course Week</th>
<th>Lesson Description</th>
</tr>
</thead>
</table>
| Four                          | 8           | Activities targeting concepts in Big Ideas #3 (Figure 3.2)  
- Hands-on exploration and discussion focused on how many water droplets PSTs could be added to the surface of a penny (Spangler, n.d.)  
- Instructor-led drawing demonstration on whiteboard and discussion for explanation of balance of forces on water droplets on penny  
- Hands-on exploration and discussion with water drop maze with plastic surface (Teach Beside Me, n.d.)  
- Hands-on exploration and discussion of adding water droplets to different surface materials (Harlen, 2001, pp. 44–45)  
- Instructor-led demonstration on whiteboard to explain balance of forces on water droplets on different surfaces  
- Hands-on exploration rolling balls on different flat surfaces  
- Instructor-led drawing demonstration on whiteboard and discussion of balance of forces acting on ball to connect with balance of forces on water droplets  
- Independent PST evaluation and revision of drawings from lesson three to include new ideas based on content |
| Five                          | 9           | Finalizing Explanations for Water-force Phenomenon  
- Final observation of clipped video of “Wringing out Water on the ISS- for Science!” (Canadian Space Agency, 2013)  
- Overview of lessons and concepts covered each week with instructor providing representational drawings on whiteboard  
- Independent PST evaluation and final revision of drawings based on review of activities  
- PST-generated text-based explanations recorded in notebook |
As outlined for the conceptual framework in Chapter Two, the explicit instruction on drawing-to-reason was structured based on Quillin and Thomas’s (2015) framework with three categories of interventions, including affective, visual literacy, and modeling (Figure 3.3). The three interventions were not incorporated into lessons in a linear stepwise progression of instruction but were used interactively during instruction and the drawing process. For example, definition of graphic symbols supported the creation step of modeling, and modeling interventions provided opportunities to practice with drawing medium. Affective interventions were incorporated throughout the lessons. The specific instructional interventions that were incorporated in the series of five lessons during the semester are listed in Tables 3.3 to 3.5 based on the target of the intervention. The tables include the description from Quillin and Thomas (2015) and specific examples of the implementation during the series of lessons that focused on explicit instruction for drawing-to-reason.

Figure 3.3

*Instructional Intervention Categories for Drawing-to-Reason*

<table>
<thead>
<tr>
<th>Affective</th>
<th>Visual Literacy</th>
<th>Modeling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attitude</td>
<td>Definition of graphic symbols</td>
<td>Creation</td>
</tr>
<tr>
<td>Value</td>
<td>Drawing medium practice</td>
<td>Evaluation</td>
</tr>
<tr>
<td>Self-Efficacy</td>
<td>Translation practice</td>
<td>Revision</td>
</tr>
<tr>
<td>Interest</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note:* Specific interventions for each category are described in Tables 3.3 to 3.5
### Table 3.3

**Affective Interventions**

<table>
<thead>
<tr>
<th>Intervention Type</th>
<th>Description from Quillin &amp; Thomas (2015; Table 6)</th>
<th>ELM 420 Course Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Attitude</strong></td>
<td>“Explicitly walk through the process of creating a [drawing] for students before asking them to make their own”</td>
<td>- Provided overview of recommended practices and graphic symbols</td>
</tr>
<tr>
<td></td>
<td>“Use positive and encouraging language when referring to drawing in the classroom”</td>
<td>- Modeled Cartesian diver explanation (See Figure 3.5)</td>
</tr>
<tr>
<td></td>
<td>- Provided positive feedback on drawings</td>
<td>- Provided positive feedback on drawings</td>
</tr>
<tr>
<td><strong>Interest</strong></td>
<td>“Reduce the perceived costs or actual costs of drawing-to-learn”</td>
<td>- Allotted adequate class time &amp; supplies</td>
</tr>
<tr>
<td></td>
<td>“Increase the perceived rewards or actual rewards of drawing to learn”</td>
<td>- Included praise for drawing inclusion in lesson plan feedback</td>
</tr>
<tr>
<td><strong>Self-efficacy</strong></td>
<td>“Explicitly define expectations to assuage students concerns about their drawing ability”</td>
<td>- Gave full credit for completion of work</td>
</tr>
<tr>
<td></td>
<td>“Model the expected behavior and provide opportunities for practice with sufficient scaffolding for complex models”</td>
<td>- Clarified that purpose was to draw ideas</td>
</tr>
<tr>
<td></td>
<td>- Clarified not being judged on artistic ability or drawing aesthetics</td>
<td>- Clarified not being judged on artistic ability or drawing aesthetics</td>
</tr>
<tr>
<td></td>
<td>- Provided feedback or questions only about their drawn ideas to prompt reasoning</td>
<td>- Provided feedback or questions only about their drawn ideas to prompt reasoning</td>
</tr>
<tr>
<td><strong>Value</strong></td>
<td>“Refer to visuals used in the classroom or homework explicitly as models to show their pervasiveness and value”</td>
<td>- Provided examples for Cartesian diver, water molecules and general force &amp; motion</td>
</tr>
<tr>
<td></td>
<td>“Use persuasion (such as call to authority by referring to famous or familiar scientists) to communicate the value of drawing models in [science]”</td>
<td>- Multiple iterations of drawing</td>
</tr>
<tr>
<td></td>
<td>- Referred to Cartesian diver drawings as models</td>
<td>- Referred to water molecules drawings as models</td>
</tr>
<tr>
<td></td>
<td>- Referred to water molecules drawings as models</td>
<td>- Referred to water molecules drawings as models</td>
</tr>
<tr>
<td></td>
<td>- Watched Edutopia video on value of drawing</td>
<td>- Watched Edutopia video on value of drawing</td>
</tr>
<tr>
<td></td>
<td>- Discussed personal use of drawing as a former practicing scientist and engineer</td>
<td>- Discussed personal use of drawing as a former practicing scientist and engineer</td>
</tr>
<tr>
<td>Intervention Type</td>
<td>Description from Quillin &amp; Thomas (2015; Table 7)</td>
<td>ELM 420 Course Implementation</td>
</tr>
<tr>
<td>-------------------</td>
<td>-----------------------------------------------</td>
<td>---------------------------------</td>
</tr>
</tbody>
</table>
| Definition of graphic symbols | “Explicitly define the symbols used in class” | - Introduced and reviewed Foundational Images and Scale Tools (Figure 3.4)  
- Provided examples of drawing with conventions |
| Drawing medium practice | “Give students opportunities to practice using the drawing medium that will be used and assessed in class” | - Practiced drawing of Cartesian diver phenomenon based on guidance from instructor with same pencil and paper format  
- Drew multiple times to revise explanations on the intermolecular water force phenomenon |
| Translation practice | “Give students opportunities to practice translating text to drawings” | - Encouraged use of notebooks to record drawings to accompany recorded textual information from class  
- Prompted PSTs to draw information included as text in their phenomenon explanations |
|                      | “Give students opportunities to practice translating ‘horizontally’ from one drawing to another at the same scale” | - Modeled and practiced drawing different models of water molecules in notebook for horizontal translation |
|                      | “Give students opportunities to practice translating ‘vertically’ from a drawing at one scale to a drawing at another scale” | - Used magnification tool to depict smaller scale of molecules in matter |
|                      | “Give students opportunities to practice translating drawings to text” | - Wrote explanations after completing drawn explanations |
## Table 3.5

**Modeling Interventions**

<table>
<thead>
<tr>
<th>Intervention Type</th>
<th>Description from Quillin &amp; Thomas (2015; Table 8)</th>
<th>ELM 420 Course Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creation</td>
<td>“Explicitly walk through the process of creating a [drawing] for students before asking them to make their own” “Explicitly point out the difference between surface features and structural features (the underlying relationships, processes, functions, and principles in the models)” “Demonstrate the flexibility of models in the classroom by showing and prompting alternate versions of the same model”</td>
<td>- Modeled example of drawing an explanation of Cartesian diver phenomenon - Used initial Cartesian diver drawings to focus on what is considered an observable feature, versus the non-observable structures, processes, and relationships that explain a phenomenon - Showed multiple ways to draw ideas for the balance of forces in the Cartesian diver explanation - Included different ways to build physical models of water molecules and multiple ways to draw water molecules</td>
</tr>
<tr>
<td>Evaluation</td>
<td>“Prompt students to check the quality of their [drawings] to ensure that they include all the essential elements in an accurate way”</td>
<td>- Added clarification questions on drawings - Added prompts to drawings to focus on aspects of explanation they were challenged to express visually - Encouraged students to review their prior version of drawing after each lesson covering new concepts about intermolecular water forces</td>
</tr>
<tr>
<td>Revision</td>
<td>“Prompt students to make improvements of their [drawings] based on their (or someone else’s) evaluation or it”</td>
<td>- PSTs revised original drawings as they gathered evidence in lessons</td>
</tr>
</tbody>
</table>
As part of the visual literacy instruction (Table 3.4), the instructor initially provided definitions for relevant graphic symbols (Figure 3.4). These graphic symbols included foundational images for vectors, particles, and waves, and scale tools, including frames and magnifiers. During the drawing process, PSTs were encouraged to depict the dynamic nature of phenomena with temporal (i.e., before, during, and after) or spatial (earth vs space) frames and to include non-observable structures, processes, and relationships along with observable features. The instructor also modeled the use of the graphic symbols on the class whiteboard to show how they could be used to include more salient features when drawing-to-reason (see Figure 3.5).

Figure 3.4

*Graphic Symbols Used for Visual Literacy Instruction*

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
<th>Graphic Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foundational Images</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vector</td>
<td>Used to represent direction, magnitude, force, pressure, velocity, acceleration, momentum, displacement, and rotational motion</td>
<td><img src="image" alt="Vector" /></td>
</tr>
<tr>
<td>Particles</td>
<td>Used to represent the microscopic parts of matter that make up all forms of matter including solids, liquids and gases.</td>
<td><img src="image" alt="Particles" /></td>
</tr>
<tr>
<td>Scale tools</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frames</td>
<td>Used to illustrate a sequence, progression, or continuous series</td>
<td><img src="image" alt="Frames" /></td>
</tr>
<tr>
<td>Magnifier</td>
<td>Enlarges and reduces the geometric scale of an object, process, or phenomena</td>
<td><img src="image" alt="Magnifier" /></td>
</tr>
</tbody>
</table>
Figure 3.5

Instructor-modeled drawing of explanation for Cartesian diver phenomenon

Note: Reece’s copied version of instructor drawing on white board
Data Collection

Table 3.6 outlines the specific data source according to the sub-questions that were used to assess learning outcomes based on affective characteristics, SK, and PCK. The quantitative and qualitative data were collected concurrently during the research study. See Figure 3.6 for timing of the data collection during the 14-week semester relative to the series of lessons with explicit instruction on drawing-to-reason. While all PSTs in the course participated and produced all coursework and assignments that serve as a data source for the research study, only sources of evidence from consenting PSTs were used for the analysis. The semi-structured interviews were conducted only with consenting participants after the submission of final grades for the semester. A more detailed description of the data sources will be provided in the next section.

Table 3.6

Sources of Evidence for Measuring Learning Outcomes

<table>
<thead>
<tr>
<th>Sub-question One</th>
<th>Sub-question Two</th>
<th>Sub-question Three</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Science teaching efficacy beliefs (STEB) from T-STEM instrument</td>
<td>2. Semi-structured Interviews</td>
<td>2. Semi-structured Interviews</td>
</tr>
<tr>
<td>3. Semi-structured Interviews</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. Sub-question one explores learning outcomes regarding affective characteristics, sub-question two explores SK learning outcomes, and sub-question three explores PCK learning outcomes.
Figure 3.6

Data Collection Timeline During the 14-week Semester

Note: This timeline shows the 14 weeks of classes and field experiences for the PSTs’ science methods course. The weeks with lessons focused on explicit instruction on drawing-to-reason are indicated below the timeline axis from week four to ten. The weeks that PSTs were in the field to facilitate their science lessons also are indicated below the timeline axis. The data sources are categorized based on primary data strand.
Data Sources

Each of the specific data sources listed in Table 3.6 are discussed in more detail below. Additional course artefacts that were used for providing context about each PST are also described.

ATLAST Multiple-choice Force & Motion Assessment

This assessment was used to provide context about the PSTs’ general knowledge about force and motion. It was developed by the Assessing Teacher Learning About Science Teaching (ATLAST) project at Horizon Research, Inc. ATLAST was funded by the National Science Foundation under grant number DUE-0335328 (Horizons Research Inc., 2011).

The ATLAST multiple-choice instrument includes questions that assess a range of sub-ideas regarding force & motion. In addition, the questions are structured to assess science knowledge of teachers in three ways: (a) ability to recall conceptual ideas about force & motion, (b) ability to use their content knowledge for student understandings, and (c) ability to use their knowledge for instructional purposes. For this research study, a subset of the questions developed by Horizons Research Inc. were selected for use in the research to limit the time needed for assessment and to minimize potential testing fatigue. The questions were selected based on the relevance of the force & motion sub-ideas to the course activities and to include all three ways the teachers might apply their knowledge to answer the questions. See Table 3.7 for the sub-ideas included in the subset of questions from ATLAST. Based on the terms of use with Horizons Research, the specific questions cannot be included in this document. Appendix A includes the question numbers from the original ATLAST assessment with the associated sub-ideas and type of knowledge application. The original ATLAST instrument can be requested.
Table 3.7

*Sub-Ideas Included in ATLAST Questions for PSTs*

<table>
<thead>
<tr>
<th>Sub-Idea</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>A force is a push or pull interaction between two objects, and has both magnitude and direction</td>
</tr>
<tr>
<td>B</td>
<td>All of the forces acting on an object combine through vector addition into a net force; they either balance each other out (net force is zero) or act like an unbalanced force (net force is not zero)</td>
</tr>
<tr>
<td>C</td>
<td>A force diagram uses arrows to represent the forces acting on an object at a particular moment. The length of the arrow represents the relative magnitude of the force. The direction of the arrow represents the direction of the force acting on the object.</td>
</tr>
<tr>
<td>D</td>
<td>If an object is moving faster and faster, then there is a net force acting on the object in the same direction as the motion</td>
</tr>
<tr>
<td>E</td>
<td>If an object is moving faster and faster, then there is a net force acting on the object in the same direction as the motion</td>
</tr>
<tr>
<td>I</td>
<td>If an object has constant speed in a straight line (or zero speed), then there is no net force acting on the object. This can occur either when the forces on the object are balanced or there are no forces exerted on the object.</td>
</tr>
<tr>
<td>J</td>
<td>The force of friction acts to oppose the relative motion of two objects in contact. Friction acts on both objects along the surfaces in contact with each other. The magnitude of friction depends upon the properties of the surfaces and how hard the objects are pushed together</td>
</tr>
</tbody>
</table>
The multiple-choice assessments were administered prior to the start of the unit of lessons on intermolecular water forces and one week after the last lesson on drawing-to-reason about the intermolecular water force phenomenon (see Figure 3.6 for semester timeline). Three different versions of the ATLAST instrument were used for the assessment. Each version had a different randomized order for the included questions. Each PST received the same randomized version for both testing occasions. All versions were administered in paper and pencil format with one question per page. Scrap paper was also provided in case it was needed for making notes while completing the assessment. Both the test packets and any additional paper with notes were collected from the PSTs after completing the assessment.

Course Artifacts

While not analyzed for learning outcomes, several course assignments were used to support the descriptions of the PSTs and provide context about their prior science and teaching experiences. In addition, the artifacts were used to provide examples supportive of findings from the quantitative and qualitative data analysis. Course artifacts included PSTs’ written responses on a Page Keeley (2010) probe “Doing Science”, reflections on their science lessons for the field experiences, and instructor informal observation memos about the PSTs’ engagement and discussion during the in-person class meetings. Although all course meetings were video-recorded for reference if needed, they were not used for this study.

PST-Generated Drawings

PSTs generated a series of five drawings, which were used as data artifacts for this study. The first drawing was the PSTs’ explanation for the Cartesian diver phenomenon, which was generated on the first week of the series of lessons with explicit instruction on drawing-to-reason (see Table 3.2 for lesson series description). The PSTs were provided plain, 8.5 x 11-inch sheets
of paper, pencils, and other drawing tools to use for their drawings. The remaining four drawings were generated in weeks two to five as the PSTs iteratively created, evaluated, and revised their drawn explanations for the difference in observed water behavior when a washcloth was wrung out in space versus on earth. Throughout the dissertation, these four drawing versions will be referred to as the water-force phenomenon drawings.

For the first version of the water-force phenomenon drawing, PSTs were given 11 x 17-inch pieces of plain, white paper, pencils, and other drawing instruments to use at their discretion. Subsequent versions of the water-force phenomenon drawings were generated by evaluating and revising the previous version. The instructor captured images of each iteration of the drawings with the camera on her Samsung Galaxy phone after each week of lessons. The captured images were stored on a secure google drive for the dissertation research data and used to recreate 11 x 17-inch prints for each version of the water-force drawings to use for data analysis.

**Science Lesson Plans for Field Experiences**

PSTs created two lesson plans during the semester to guide their science instruction during the two field-experience weeks. Their first science lesson focused on leading a Paige Keeley formative assessment probe (Keeley, 2018) with students from their assigned elementary, field-experience classroom. The first lesson plan was completed on the fifth week of the semester, which was one week after PSTs were introduced to drawing-to-reason and created their drawn explanation for the Cartesian diver phenomenon (See timeline in Figure 3.6). The second lesson plan focused on facilitating a discrepant event (Fensham & Kass, 1988; González-Espada et al., 2010) and was completed two weeks after the last lesson on drawing-to-reason about the intermolecular water force phenomenon (See timeline in Figure 3.6).
Semantic Differential Attitude (SDA) Survey Instrument

The SDA survey administered to the PSTs was based on the Attitude toward the Subject of Chemistry Instrument developed by Bauer (2008), who used it to assess attitudes of undergraduate students regarding chemistry. The instrument included the statement, “Chemistry is…”, along with a series of bipolar adjectives with a rating scale from one to seven between the two adjectives. Bauer (2008) designed the survey with physical features to help respondents focus on the adjectives and the response range. The scale rating range was one to seven to strengthen reliability and to provide adequate distinction among choices. Pairs of adjectives were listed on the same line with the scale rating in between. Some pairs were listed with more negative adjectives on the left and others with the more negative adjective on the right to help minimize response bias. In addition, the statement on which respondents were basing their ratings was prominently featured on the top of the page in large, bold, capitalized letters.

The SDA instrument for this research was formatted as specified by Bauer (2008) except for the targets of attitude assessment. While the main attitudinal targets for the survey in this research study were physical science and drawing, questions were included for the other two elementary science strands, i.e., life science and earth science, and for two other science disciplinary practices, i.e., science observations and science investigations. Using physical science as an example for the target of attitude, the SDA questions were worded as “Physical Science is…” Separate questions with the same set of bipolar were included for each target. The PSTs were asked to respond by indicating on a scale from one to seven, which bipolar adjective they most associated with the target. See Appendix C for the lists of bipolar adjectives in the survey. The survey was administered via Qualtrics at the beginning and the end of the semester.
In both testing occasions for the survey, the order of questions and pairs of adjectives within each question were randomized.

**Semi-structured Interviews.**

After the final grades were submitted for the spring semester, the consenting PSTs participated in semi-structured interviews with the researcher via Zoom. The interviews were video-recorded and transcribed by Rev for data analysis. The interview questions (Appendix D) were designed to generate self-reported qualitative data for all three sub-questions used to explore the PSTs’ learning outcomes during the course, as well as questions about their prior science and drawing experiences and general orientation towards teaching science. Because the interviews provided self-reported data with the researcher as the interviewer, the PSTs were encouraged at the beginning of the interview to respond as honestly and openly as possible. To help minimize PSTs’ perceptions that course grades were influenced by how they responded since the interviews were facilitated by the instructor, the interviews were conducted after final grades for the semester are submitted. In addition, as discussed in more detail in the section on issues of trustworthiness, the researcher as the course instructor purposefully worked to establish relationships with the PSTs during both the prior fall semester in the engineering methods course and the spring semester of the science methods course in which research data was collected. The PSTs transcribed interviews can be found in Appendix F.

**T-STEM Survey Instrument**

Quantitative data on PSTs’ self-efficacy in science teaching was obtained via the Teacher Efficacy and Attitudes Toward STEM (T-STEM) Instrument (Friday Institute for Educational Innovation, 2012). The T-STEM instrument was developed to assess both the teacher’s self-efficacy for teaching the different STEM disciplines, as well as their belief that their teaching
positively influences student outcomes. For this research, the survey was modified to include only questions regarding science and focused on science teaching efficacy beliefs (STEB).

The survey was administered via Qualtrics at the beginning and the end of the semester. For both testing occasions, the question order was randomized within the blocks that targeted the STEB construct. See Appendix B for the survey instrument questions.

*Written Explanation of Water-Force Phenomenon*

After completing the final version of their drawings for the water-force phenomenon in the last lesson with explicit instruction on drawing-to-reason (see Table 3.2 for description of lesson series), the PSTs were asked to write an explanation in their notebooks to share with the instructor. Their own drawings were available for reference while they constructed their written explanations, however, they did not discuss their drawings or ideas with either their peers or the instructor before or while writing.

*Data Analysis*

As discussed in the conceptual framework background in Chapter Two, the purpose of incorporating explicit instruction on drawing-to-reason about force-related phenomena in their science methods course was to support PST’s knowledge for incorporating drawing as an instructional strategy in the elementary science classroom. The three sub-questions for this research explored learning outcomes regarding *affective characteristics*, *SK*, and *PCK* (See Figure 2.1 in Chapter Two).

The learning outcomes were operationalized for measurement via qualitative and quantitative analysis of multiple sources of evidence, including semi-structure interviews, physical artifacts, and survey instruments. The research design for this mixed methods study was a single case, which was the science methods course with explicit instruction on drawing-to-
reason. The PSTs were included as embedded subunits in the overall case; therefore, the initial unit of analysis were the individual PSTs. The qualitative and quantitative data were synthesized for each PST, and descriptions for all PSTs were integrated to create an overall interpretation of the learning outcomes regarding affective characteristic, SK, and PCK for the science methods course with explicit drawing instruction. The analysis of the qualitative and quantitative data for each PST is described in more detail in the following sections, which are organized based on the three guiding sub-questions for the research.

Sub-question One

This section describes the data analysis for addressing sub-question one, which explored PSTs’ learning outcomes regarding affective characteristics towards drawing, physical science, and science teaching. For this sub-question both qualitative and quantitave data were used as operationalized measures of PSTs’ affective characteristics at the beginning and the end of the science methods course that incorporated explicit instruction on drawing-to-reason. Table 3.8 outlines the affective characteristics that were measured for this research, their conceptual definitions, and the operationalized definitions for this study. Primary data (Figure 3.7) for quantitative data strand included self-reported responses from the SDA Instrument and T-STEM survey (Unfried et al., 2022). Primary data (Figure 3.7) for qualitative data stand were the PSTs’ responses during semi-structured interviews at the end of the semester.

The data was synthesized for each PST subunit based on a convergence model (Figure 3.8) in which qualitative and quantitative data were analyzed concurrently to triangulate findings and then combined to create a description of learning outcomes for each PST. The overall understanding for the case, i.e. the science methods course, was based on integration of the findings for all four PSTs.
### Table 3.8

**Conceptual and Operationalized Definitions and Measures for Affective Characteristics**

<table>
<thead>
<tr>
<th>Affective Characteristic*</th>
<th>Conceptual Definition</th>
<th>Operationalized Definition</th>
<th>Measures</th>
</tr>
</thead>
</table>
| Attitude                 | "Tendency to respond with some degree of favorableness or unfavorableness" (Fishbein and Ajzen, 2009, p. 76). | PSTs’ favorable or disfavorable evaluation of science drawing, physical science, or science teaching | Quantitative: SDA responses  
Qualitative: Deductive content analysis interviews |
| Interest                 | Individual’s disposition to learn more about or engage with an idea, object, or activity (Hidi & Reninger, 2006) | PSTs’ disposition to want to learn more about or to engage with drawing-to-reason or physical science for their own learning or for teaching | Qualitative: Deductive content analysis of interviews |
| Self-efficacy            | Individual’s belief in their ability to effectively engage with activities such as teaching or learning (Bandura, 1997). Colloquially referred to as a “can do” attitude. | PSTs’ beliefs about their ability to effectively engage with drawing or teach science | Quantitative: T-STEM instrument  
Qualitative: Deductive content analysis of interviews |
| Value                    | Individual’s evaluation of the importance or acceptability of a targeted idea, object, or activity based on cultural norms or personal beliefs (Rokeach, 1973; Tyler, 1973). | PSTs’ evaluation of the importance of drawing-to-reason as a strategy for elementary student learning | Qualitative: Deductive content analysis of interviews |

*All the affective characteristics were considered latent constructs with affective, cognitive, and behavioral components (Anderson & Bourke, 2000).
Figure 3.7

Qualitative and Quantitative Data Strands to Address Sub-Question One

**QUAL**

Deductive Content Analysis of Semi-structured Interviews

**Subunit Data Synthesis**

- Avery Learning Outcomes
- Eileen Learning Outcomes
- Joan Learning Outcomes
- Reece Learning Outcomes

**QUAN**

SDA Responses

T-STEM Responses

**Overall Case Interpretation of Learning Outcomes for Affective Characteristics**

*Note:* Data for the qualitative (QUAL) and quantitative (QUAN) strands were analyzed and synthesized to provide descriptions for the embedded subunits (i.e., the individual PSTs). The subunit descriptions were integrated for an overall case understanding of PSTs’ learning outcomes based on affective characteristics.
Figure 3.8

Triangulation Design: Convergence Model

Note. Convergent triangulation design based on Creswell and Plano Clark (2007). Qualitative (QUAL) and quantitative (QUAN) data are analyzed, then compared and contrasted to provide synthesized descriptions for each PST subunit. The descriptions are integrated to provide and overall interpretation for the case study.
SDA Survey Data Analysis. During the development of the SDA instrument, Bauer (2008) used an exploratory factor analysis on the collected responses from subjects (n=379) and identified multiple factors with similar response patterns (See Table 3.9 for the loading factors). Bauer (2008) attributed three of the factors for the bipolar adjectives to 1) interest and utility, 2) anxiety, and 3) intellectual accessibility. An additional set of bipolar adjectives, which did not load significantly to a fourth factor, did have similar response loadings on the other three factors, therefore, Bauer (2008) grouped them and attributed the set to emotional satisfaction. The Cronbach $\alpha$ values were 0.83, 0.77, 0.78, and 0.79 for interest and utility, anxiety, intellectual accessibility, and the emotional satisfaction set, respectively.

The SDA survey included an adjective pair (safe: dangerous) that loaded to a fourth factor, which Bauer (2008) attributed to fear. However, Bauer defined this fear as the perception of a physical threat versus a cognitive fear towards a discipline or practice. Therefore, the factor attributed to fear was not included in the analysis of PSTs’ attitudes.

For this study, the PSTs’ SDA responses at both the beginning and end of the semester were analyzed based on the factors and set of adjectives reported in Bauer (2008). The statistical software program Stata 17.0 Basic Edition (Stata Corp, College Station, Texas) was used for data cleaning, manipulation, and analysis of the PSTs’ responses to the SDA survey. Individual PST values were calculated at the beginning and end of semester for drawing and for physical sciences by summing the self-reported scores for the respective adjective pairs for each factor or the set of adjectives identified by Bauer (2008).
**Table 3.9**

*Constructs from SDA Survey and Factor Loading Profiles Reported from Bauer (2008)*

<table>
<thead>
<tr>
<th>Polar Adjectives&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Factor 1&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Factor 2&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Factor 3&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Interest and Utility</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>worthwhile</td>
<td>useless&lt;sup&gt;a&lt;/sup&gt;</td>
<td>−0.85</td>
<td>−0.01</td>
</tr>
<tr>
<td>worthless</td>
<td>beneficial</td>
<td>−0.79</td>
<td>−0.10</td>
</tr>
<tr>
<td>good</td>
<td>bad&lt;sup&gt;a&lt;/sup&gt;</td>
<td>−0.71</td>
<td>−0.05</td>
</tr>
<tr>
<td>interesting</td>
<td>dull&lt;sup&gt;a&lt;/sup&gt;</td>
<td>−0.67</td>
<td>−0.32</td>
</tr>
<tr>
<td>exciting</td>
<td>boring&lt;sup&gt;a&lt;/sup&gt;</td>
<td>−0.58</td>
<td>−0.38</td>
</tr>
<tr>
<td><strong>Anxiety</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>tense</td>
<td>relaxed</td>
<td>−0.14</td>
<td>−0.75</td>
</tr>
<tr>
<td>work</td>
<td>play</td>
<td>−0.06</td>
<td>−0.74</td>
</tr>
<tr>
<td>scary</td>
<td>fun</td>
<td>−0.35</td>
<td>−0.60</td>
</tr>
<tr>
<td>insecure</td>
<td>secure</td>
<td>−0.34</td>
<td>−0.53</td>
</tr>
<tr>
<td>disgusting</td>
<td>attractive</td>
<td>−0.42</td>
<td>−0.53</td>
</tr>
<tr>
<td><strong>Intellectual Accessibility</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>complicated</td>
<td>simple</td>
<td>−0.03</td>
<td>−0.13</td>
</tr>
<tr>
<td>confusing</td>
<td>clear</td>
<td>−0.24</td>
<td>−0.33</td>
</tr>
<tr>
<td>easy</td>
<td>hard&lt;sup&gt;a&lt;/sup&gt;</td>
<td>−0.13</td>
<td>−0.18</td>
</tr>
<tr>
<td>challenging</td>
<td>unchallenging</td>
<td>−0.29</td>
<td>−0.36</td>
</tr>
<tr>
<td>comprehensible</td>
<td>incomprehensible&lt;sup&gt;a&lt;/sup&gt;</td>
<td>−0.38</td>
<td>−0.03</td>
</tr>
<tr>
<td><strong>Emotional Satisfaction</strong>&lt;sup&gt;c&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pleasant</td>
<td>unpleasant&lt;sup&gt;a&lt;/sup&gt;</td>
<td>−0.50</td>
<td>−0.44</td>
</tr>
<tr>
<td>comfortable</td>
<td>uncomfortable&lt;sup&gt;a&lt;/sup&gt;</td>
<td>−0.48</td>
<td>−0.43</td>
</tr>
<tr>
<td>chaotic</td>
<td>organized</td>
<td>−0.44</td>
<td>−0.34</td>
</tr>
<tr>
<td>satisfying</td>
<td>frustrating&lt;sup&gt;a&lt;/sup&gt;</td>
<td>−0.41</td>
<td>−0.30</td>
</tr>
</tbody>
</table>

<sup>a</sup>Reversed score on adjective pair before analysis. <sup>b</sup>Loadings greater than |0.5| were considered strong by Bauer (2008) for original analysis (n=379). <sup>c</sup>Bauer (2008) grouped this set of adjectives together because they did not load strongly to any of the four factors, but did have similar loading to factors 1 to 3.
**T-STEM Survey Data Analysis.** PST responses on the T-STEM instrument survey (Unfried et al., 2022) were analyzed based on the constructs for science teaching efficacy and beliefs (STEB). The statistical software program Stata 17.0 Basic Edition (Stata Corp, College Station, Texas) was used for data cleaning, manipulation, and analysis of the PSTs’ responses on the T-STEM survey. Upon analysis of the data, I discovered that one question had been inadvertently included twice. Summation of beginning and end of semester response values were calculated for for STEB at the beginning and end of semester. The PSTs’ STEB was calculated as a percentage of the maximum scale value for the STEB construct in the instrument.

**Analysis of Semi-structured Interviews for Affective Characteristics.** Qualitative analysis of the transcribed, semi-structured interviews was conducted by content analysis with a deductive approach (Elo & Kyngäs, 2007). Deductive content analysis was selected because the goal of the analysis was to identify the frequency of PST-mentioned affective characteristics (Table 3.8), including their directionality (i.e. positive or negative); target (i.e. drawing, science, or science teaching); and timing (i.e. after explicit drawing instruction compared to the beginning-of-semester).

While deductive content analysis is not a prescribed set of steps, it is composed of three phases, which focus on preparation, organization, and reporting (Elo & Kyngäs, 2007). Figure 3.9 provides a detailed schematic for the process of deductive content analysis of the various data artifacts for this study based on the three phases. The details for the structuring of the category matrix for each data source are described in the subsections for their analysis.
Figure 3.9

Overview of This Study’s Deductive Content Analysis Process

**Preparation**

- Selected unit of analysis:
  - Individual PST interviews (affective characteristics, SK, PCK)
  - Individual drawings (Cartesian diver & four versions of water force drawings)
  - Individual lesson plans (First and second field experience weeks)
- Reviewed sources for familiarity and to make preliminary sense of data
- Created perceptual inventory of PST-generated drawings

**Organizing**

- Developed structured analysis matrices:
  - Affective characteristics in interviews (Figure 3.10, Table 3.10)
  - Conceptual ideas for water-force phenomenon in drawings and written explanation (Figure 3.13, Table 3.11)
  - Modeling aspects for drawings (Figure 3.14-3.17, Table 3.13)
  - New SK knowledge in interviews (Table 3.14)
  - PCK based on modeling aspects in interviews and lesson plans (Figure 3.25, Table 3.15)
- Coded manifest data based on categories in analysis matrices
- Looked for relations between coded categories in study
  - Affective characteristics and targets
  - Prior to and after instruction with affective characteristics, SK, PCK
  - Instructional interventions with affective characteristics, SK, PCK
- Triangulated existence/frequency results with quantitative methods
- Compared correspondence with relevant literature references

**Reporting**

- Documented analysis process
- Synthesized results for each PST subunit based on research questions
- Integrated results to interpret learning outcomes for case (i.e. science methods course)
During the preparation phase, the unit of analysis is specified, and the researcher becomes immersed in the data to gain a sense of what it contains and might mean. Immersion in the data guides structuring the analysis matrix and coding decisions, such as coding of only manifest data or combining deductive and inductive approaches. During the organization phase, the analysis matrix is structured, data sources are analyzed according to the coding scheme, and categories are explored for trends and patterns, as well as for correspondence with other categories. Finally, the reporting phase includes documenting the process of the analysis and the findings (Elo & Kyngäs, 2007).

Structuring of the category matrix during the organization phase was based on the domain referencing technique from Anderson and Bourke (2000). The affective characteristics for the content analysis included attitude, self-efficacy, interest, and value, which had been targeted during the explicit instruction on drawing-to-reason (Anderson & Bourke, 2000; Quillin & Thomas, 2015). For this technique, the affective characteristics had both a conceptual definition, which described the meaning in abstract terms based on literature references, and an operationalized definition, which described the meaning in more concrete terms relevant to this study and included directionality of the affective characteristics. The operationalized definition included key verbs and adjectives as anchoring samples for the affective characteristics and their associated directionality. The process for structuring the category matrix for the affective characteristics during the organization phase of the deductive content analysis is shown in Figure 3.10. Peer debriefing was included at various steps in the process to provide a measure for trustworthiness for the analysis.
Note: Schematic of structuring the category matrix during the organization phase for the
deductive content analysis of the PSTs’ interviews. The final matrix was an interative process of
defining categories and comparing with the text in the interviews. Steps that included peer
debriefing as a validation check to support trustworthiness of the analysis are indicated with
arrows.
The first step of structuring the matrix was to define the different categories and provide conceptual definitions based on the extant literature (Anderson & Bourke, 2000; Bandura, 1997; Fishbein & Ajzen, 2009; Hidi & Reninger, 2006; Rokeach, 1973; Tyler, 1973). The affective characteristics were grouped into two main categories based on their positive or negative directionality towards a target. The positive and negative affective characteristics were both divided into generic categories for attitude, interest, self-efficacy and value. See conceptual definitions of the affective characteristics in Table 3.8. In addition, targets of the affective characteristics were included as a main category and divided into generic categories for drawing, physical science, and science teaching. Timing for the expressed affective characteristic was also a main category, which included generic categories of “prior to” or “after” to indicate PSTs’ reference to the beginning or the end of the semester. The final main category was the explicit drawing intervention, which included the generic categories of affective, visual literacy, and modeling based on the Quillin and Thomas (2015) instructional framework used in the study.

In the second step of the structuring process, initial operationalized definitions were created for the affective characteristics based on the conceptual definitions, and representative adjectives and verbs were selected as anchoring samples for the positive and negative affective characteristics. Operationalized definitions and anchoring samples for the target, timing, and instructional intervention categories were specified also. The draft category matrix was used to perform a preliminary coding of one of the PSTs’ transcribed interviews in Atlas.ti (Version 23). Within the interview, quotes that explicitly contained adjectives and verbs corresponding with the defined categories were highlighted, but additional quotes were also flagged if the wording implicitly reflected the affective characteristics. The matrix category was reviewed and updated based on the quotes from the first PST interview.
The second iteration of the matrix structuring included an additional PST’s interview, which was compared with the revised category matrix to determine if any additional key terms needed to be included with the operationalized definitions for each category. After finalizing the matrix (See Table 3.10), all four PSTs’ interviews were analyzed for the frequency of quotes that corresponded to the included categories. After the coding of all interviews was completed, Atlas.ti was used to explore correspondences between the categories to look for associations between the affective characteristics and the targets, timing, and instructional interventions. The coding results were also triangulated with the findings from the SDA and T-STEM.
Table 3.10

*Final Category Matrix for Learning Outcomes based on Affective Characteristics*

<table>
<thead>
<tr>
<th>Generic Category</th>
<th>Operationalized Definition</th>
<th>Interview Examples</th>
</tr>
</thead>
</table>
| **Positive attitude** | PSTs’ favorable evaluation of target (see target codes in table below). Key verbs examples include like and enjoy. | [Avery] “[revisiting my drawing] was something that I really liked”  
[Eileen] “I really liked the penny activity”  
[Reece] “But I think [drawing’s] a really cool way for students to communicate their ideas.” |
| **Positive Interest** | PSTs’ disposition to want to learn more about or to engage with target (see target codes in table). Key verbs include will do and interested. | [Avery] “I find a little bit more interesting…”  
[Eileen] “I do [envision incorporating drawing]”  
[Joan] “Definitely, yeah [envision incorporating drawing]”  
[Reece] “and I will definitely be including [drawing] in my future science teaching” |
| **Positive Self-Efficacy** | PSTs’ beliefs about their ability to effectively engage with or implement a target (see target codes in table). Key verbs include can and able to. | [Avery] “But, it was a way for us to build upon that knowledge and even understand, ‘Okay, I didn't have maybe the correct idea at first with this drawing,’ …to be able to see how your thinking has changed.”  
[Eileen] “I think I know more places to get that knowledge now”  
[Joan] “I was able to think through my stuff more and think through my thinking more by drawing”  
[Reece] “I feel very prepared now” |
| **Positive Value** | PSTs’ evaluation of the importance of target (see target codes in table). Keywords include useful, helpful, and important. | [Avery] “…it’s important to understand that there's a purpose for their drawing…”  
[Eileen] “I see a bigger importance to having them do science…”  
[Joan] “…But I can see it [drawing] as being helpful now …because we did it so much in our class”  
[Reece] “…probably would help students understand…” |
<table>
<thead>
<tr>
<th>Generic Category</th>
<th>Operationalized Definition</th>
<th>Interview Examples</th>
</tr>
</thead>
</table>
| Negative attitude     | PSTs’ disfavorable evaluation of target (see target codes in table). Key verb examples include dislike or hate. | [Eileen] “…something that personally I didn't like in school.”  
[Reece] “All my teacher would do was send us Google slides and be like, "Okay, you have to memorize all this information." And it really didn't make sense because it was just all written and there wasn't really any diagrams or hands on experimenting…” |
| Negative Interest     | PSTs’ disposition to not want to learn more about or to engage with target (see target codes in table). | No quotations for this code but included because in final codebook                                                                                   |
| Negative Self-Efficacy| PSTs’ beliefs about their lack of ability to effectively engage with or implement target (see target codes in table). Key verbs include can’t and not able to. | [Avery] “Some of these scientific ideas, I don't even know if I fully understand them to be able to explain to students…”  
[Eileen] “…I still don't really understand why that's the case.”  
[Joan] “… I don't know how to draw this and kind of like, I don't know how to explain this on paper.” |
| Negative Value        | PSTs’ evaluation of the lack of importance of target (see target codes in table). Keywords include not useful, not helpful, and not important. | [Avery] "… it would be a bit easier to write out those definitions and verbally explain it or in writing rather than trying to draw it out.” [Note that conveying the best way to represent not ability to draw]  
[Eileen] “…I didn't really see the point in why we were drawing for school”  
[Joan] “I think that is easier to write because you can just say like you wring out a washcloth…” [Note that conveying the best way to represent not ability to draw]  
[Reece] “Probably that the washcloth was still damp. That was definitely easier to write than draw.” [Note not conveying ability but the best way to represent] |
### Table 3.10 (continued)

<table>
<thead>
<tr>
<th>Generic Category</th>
<th>Operationalized Definition</th>
<th>Interview Examples</th>
</tr>
</thead>
</table>
| Drawing          | Reference to science drawing for any purpose including to observe, to communicate learning, to assess learning or to reason | [Avery] “was using drawings”  
[Eileen] “taught me a lot more about drawing in science”  
[Joan] “it’s easier to draw it out and it creates like a visual that is easier seen than said in words.”  
[Reece] “because I was able to just add to my drawing” |
| Physical Science | Any concept, object, or activity related to physical science or physics, such as science strand, course coursework, phenomena, or specific concepts like force and motion | [Avery] “that physics class”  
[Eileen] “Then physical science, I think there's some that I feel more confident with.”  
[Joan] “I would've probably lost some of the knowledge [about water phenomenon] that's in this picture.”  
[Reece] “especially with the physics” |
| General Science  | Any concept, object, or activity related to science in general or non-physical science strands, such as non-specific use of term science, life sciences, earth sciences, and general science courses, or coursework | [Avery] “about more earth and environmental and life sciences compared”  
[Eileen] “a little more confident in life or earth science”  
[Joan] "Earth science is a little bit more stressful in my head"  
[Reece] "I just felt more exposed to life science at a young age” |
| Teaching         | Any reference to teaching elementary science, including lesson planning as well as facilitation. Reference to teaching science included generic use of term science or mention of the specific science strands, physical, earth, and life sciences. | [Avery] “…and working with older students, I was in a third grade class”  
[Eileen] “…I think I have more strategies to teach with…”  
[Joan] “I guess when making this lesson…”  
[Reece] “I feel more prepared for teaching hands on experiments than last semester. Because we were kind of just like, "Oh, here's a lesson plan that you have to do, make it hands on.” |
### Table 3.10 (continued)

<table>
<thead>
<tr>
<th>Generic Category</th>
<th>Operationalized Definition</th>
<th>Interview Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Main Category: Timing</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prior to Instruction</td>
<td>PST reference to timing at beginning of or prior to ELM 420 science methods course</td>
<td>[Avery] “that's something that really helped me this semester”&lt;br&gt;[Eileen] “in school”&lt;br&gt;[Joan] “when I was in high school”&lt;br&gt;[Reece] “but he didn't really explain stuff very well and it was over Zoom too”</td>
</tr>
<tr>
<td>After Instruction</td>
<td>PST reference to timing during drawing instruction or the end of the ELM 420 science methods course</td>
<td>[Avery] “something ...that we did [this semester]”&lt;br&gt;[Eileen] “This semester also taught me a lot more”&lt;br&gt;[Joan] “because we did it so much in our class.”&lt;br&gt;[Reece] “I think in the end”</td>
</tr>
<tr>
<td><strong>Main Category: Explicit Drawing Intervention</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Affective Characteristics Intervention</td>
<td>Any reference to the instructor’s interventions such as positive feedback and encouragement, or course content that demonstrated value or elicited interest</td>
<td>[Avery] “[Instructor says] Okay, here's a drawing to help get your ideas out...”&lt;br&gt;[Eileen] “in your class we watched the …video…”&lt;br&gt;[Joan] “And one thing I'm just noticing right now is you kept asking us every week to add something to our drawing…”&lt;br&gt;[Reece] “What really helped me was your drawings on the board.”</td>
</tr>
<tr>
<td>Visual Literacy Intervention</td>
<td>Any reference to the foundational images and scale tools, instructor modeling drawing, or learning to draw during since in general</td>
<td>[Avery] “Specifically, I think of the one where it showed a magnifying glass zooming in and specifically labeling pictures…”&lt;br&gt;[Eileen] “…all the different drawing tools…”&lt;br&gt;[Joan] “…That came from what we were doing in class and I wanted to apply it to the lesson. And the worksheet had a before, during and after section so that they could see the change drawn out.”&lt;br&gt;[Reece] “…but I think what you did and modeled them probably would help students understand…”</td>
</tr>
<tr>
<td>Modeling Intervention</td>
<td>Any reference to the iterative cycle of create, evaluate and revise</td>
<td>[Avery] “…To be able to build upon that idea and go back and add to our drawings.”&lt;br&gt;[Joan] “…we kept going back to the same drawing…”&lt;br&gt;[Reece] “…because with drawing, you can just go back and erase if something doesn't necessarily fit your thinking anymore.”</td>
</tr>
</tbody>
</table>
Sub-question Two

This section describes the data analysis for addressing sub-question two regarding SK learning outcomes during the science methods course with explicit instruction on drawing-to-reason. Both quantitative and qualitative data analyses were used to explore how PSTs’ science ideas and drawings about force-related phenomena evolved over the series of lessons with explicit drawing instruction (Figure 3.11). The qualitative and quantitative data were analyzed concurrently to synthesize the findings for each PST subunit in the case study. The findings for each PST were used to create an overall understanding for the case (Figure 3.12).

As depicted in Figure 3.12, the data analysis for each PST subunit was synthesized based on a triangulation design with data transition for the quantitative data strand. The primary data for quantitative analysis included the series of PST-generated drawings and their written explanations. While the generated drawings and explanation were collected as qualitative data, deductive content analysis was used to generate counts and frequencies to provide quantitative measures of SK learning outcomes. The primary data for the qualitative data strand were the PSTs’ semi-structured interviews at the end of the semester in which they reflected on their SK knowledge about force and science drawing.

An additional source of quantitative data that is discussed in this section includes the PSTs’ ATLAST Force & Motion assessments at both testing occasions during the semester. The assessments were not used as a data source for the learning outcomes, however they provided context regarding the PSTs’ prior knowledge about force and motion, which was relevant for the interpretation of the PSTs’ drawings and their interview responses. Therefore, the analysis of the ATLAST assessments are included in this section.
Figure 3.11

Qualitative and Quantitative Data Strands to Address Sub-Question Two

Note: Data for the qualitative (QUAL) and quantitative (QUAN) strands were analyzed and synthesized to provide descriptions for the embedded subunits (i.e., the individual PSTs). The subunit descriptions were integrated for an overall case understanding of PSTs’ SK learning outcomes.
Figure 3.12

Triangulation Design: Data Transition Model

Note. Based on Creswell & Plano (2007) convergent triangulation with qualitative (QUAL) data transformed to quantitative (QUANT) data. The PST-generated drawings and written explanations were QUAL data sources that were converted to QUAN data with deductive content analysis to generate counts for specific codes that were used to compare changes in science ideas and drawing practices in the PSTs’ drawings over time.
ATLAST Multiple-Choice Force & Motion Assessment. PSTs’ answer choices on questions included in the ATLAST Force and Motion Assessment (Horizon Research, Inc, 2011) were compared against the best answer specified in the assessment documentation (See Appendix A for question numbers included and the best answer key). An Excel (Microsoft Office 15) spreadsheet was used to record the PSTs’ answers on the assessment both prior to and following the series of lessons on drawing-to-reason. For each testing occasion, the percentage correct was calculated based on the number of answers selected by the PST that matched the best choice in the answer key. A median percentage correct was calculated from the four PSTs’ scores for both testing occasions.

The purpose of the assessment was to understand the PSTs’ relative background knowledge about force and motion compared to the overall group, since it might be valuable for interpreting their learning outcomes. Horizons Research Inc. did not intend for the ATLAST instrument to be an assessment of an individual teacher’s knowledge; therefore, the outcomes from the ATLAST assessments were presented qualitatively without values. For each PST, bar graphs were created in Excel (Microsoft 15) that indicated the percentage correct in each testing occasion relative to the median. This information was conveyed by comparing the relative heights of the bars for each testing occasion with a horizontal line indicating the group median.

Content Analysis of Drawings and Written Explanation. The series of PSTs’ drawings generated during lessons on intermolecular water forces were analyzed by visual content analyses with a deductive approach to explore both changes in their conceptual knowledge about intermolecular water forces and their knowledge about the science practice of drawing. Their written explanations were also analyzed by deductive content analysis for conceptual knowledge about intermolecular water forces.
The deductive processes for visual content analysis of the drawings and content analysis of the written explanations were similar to the process described for deductive content analysis of the semi-structured interviews. The processes included the three phases of preparation, organization, and reporting (See Figure 3.9). During the preparation phase, the units of analysis for each PST were identified as their written explanations and individual drawings, including their drawing for the Cartesian diver phenomenon and each version of their explanation for the water-force phenomenon.

During the immersion step of the preparation phase, both the written explanations and drawings of all four PSTs were reviewed to gain an overall familiarity of the data artifacts and to note included science ideas and observed details of the phenomenon. In addition, the final version of the water-force phenomenon was used to create a perceptual inventory (Serafini, 2010) of the elements in the drawing and the drawing style of each PST. See Appendix E for the perceptual inventory of each PSTs’ final water-force drawing. The list of content from the written explanation and drawings and the perceptual inventory were integral to creating and finalizing the category matrices used for the deductive content analysis.

Additional details about the process steps for analyzing the drawings and written explanations based on the measured outcome, including intermolecular water-force knowledge and the practice of science drawing, are described in the following sections.

**Intermolecular Water Force Knowledge.** The structuring of the category matrix during the organization phase for deductive content analysis of PSTs’ drawings and written explanations is shown in Figure 3.13.
Figure 3.13

Structuring of Category Matrices for Deductive Content Analysis of Water-force Drawings and Written Explanations

Note: Schematic of the organization phase, including the interactive structuring of the category matrix, for deductive content analysis of PSTs’ water-force drawings and written explanations for conceptual knowledge about intermolecular water forces. Steps that included peer debriefing as a validation check to support trustworthiness of the analysis are indicated with arrows.
The first step of the structuring process was specification of initial matrix, which contained three main categories based on the Big Idea tree (Figure 3.2), including (a) matter composition and properties, (b) distant objects interactions, and (c) force. The generic categories in each main category were based on both the perceptual inventory list created during the preparation phase and the Big Idea tree for the water-force phenomenon. These generic categories included non-observable structures, processes, and relationships that explained why water behaved differently when wrung out from a washcloth in space versus on earth.

After specification of the initial matrix for the intermolecular water force knowledge, an initial coding was conducted with all four PSTs’ final drawings and their written explanations to determine if additional categories were needed or if the definitions for included categories should be refined to reflect the content in the PSTs’ drawings and explanations. After the categories were finalized based on findings from the initial analysis, the matrix was used to analyze all versions of the PST-generated drawings and the PSTs’ written explanations for the water-force phenomenon. See Table 3.11 for the final category matrix used for the deductive content analysis.

The deductive content analysis documented the existence, but not the frequency, of the different categories in the drawings and written explanations. In the final step of the organization phase, the counts of the different categories of non-observable structures, processes and relationships were compared among the drawing versions to explore how the PSTs’ intermolecular water-force knowledge changed over the sequence of lessons with explicit instruction on drawing-to-reason. In addition, the counts in the final drawing version and the written explanation were compared to explore similarities and differences between PSTs’ visual versus textual representations.
Table 3.11

*Category Matrix for Content Analysis of Intermolecular Water Force Knowledge*

<table>
<thead>
<tr>
<th>Generic Category</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Main Category: Matter composition and properties</strong></td>
<td></td>
</tr>
<tr>
<td>Molecular structure of water</td>
<td>Drawn or textual representation of the atomic structure of model in various forms including stick and ball, symbolic, labeled circle</td>
</tr>
<tr>
<td>Molecular charge (water polarity)</td>
<td>Drawn or textual representation of positive or negative charges on water molecules and other structural features</td>
</tr>
<tr>
<td>Particle model for matter</td>
<td>Drawn or textual representation of particles composing different states of matter</td>
</tr>
<tr>
<td>Spatial structure of liquid vs solid</td>
<td>Drawn or textual representation to indicate relative spatial arrangement and properties of different states of matter</td>
</tr>
<tr>
<td><strong>Main Category: Distant object interactions</strong></td>
<td></td>
</tr>
<tr>
<td>Gravity</td>
<td>Drawn or textual representation to indicate the force of gravity</td>
</tr>
<tr>
<td>Magnetism analogy</td>
<td>Drawn or textual representation to indicate the process of how charges attract or repel objects from each other</td>
</tr>
<tr>
<td><strong>Main Category: Force</strong></td>
<td></td>
</tr>
<tr>
<td>Adhesion of water molecules</td>
<td>Drawn or textual representation to indicate bonding between water molecule and another object such as hand or washcloth</td>
</tr>
<tr>
<td>Cohesion of water molecules</td>
<td>Drawn or textual representation to indicate bonding between two water molecules</td>
</tr>
<tr>
<td>Compression force on washcloth</td>
<td>Drawn or textual representation to indicate the force of compression acting on water adhered to washcloth</td>
</tr>
<tr>
<td>Drag force on water droplet</td>
<td>Drawn or textual representation to indicate that air resistance is acting on the falling water droplet</td>
</tr>
<tr>
<td>Unbalanced vs balanced forces</td>
<td>Drawn or textual representation to indicate how motion is dependent on all the different forces acting on an object (Newton’s 1st law)</td>
</tr>
</tbody>
</table>

*Note.* Features listed in table were used to code both the PSTs’ series of drawings and their written explanations.
**Knowledge about Drawing as a Science Practice.** For SK learning outcomes regarding drawing as a science practice, the unit of analysis was each of the individual drawings from the series on the water-force phenomenon and the Cartesian diver drawing. The process for structuring the category matrix that was used for deductive content analysis of the PSTs’ drawings was similar to the process described for affective characteristics. See Figure 3.14 for a schematic of the structuring process during the organization phase for the content analysis.

As outlined by Quillin and Thomas (2015) and Ainsworth (2011), there are multiple purposes for the incorporation of drawing as a science practice in the classroom, including drawing-to-reason, which is a form of modeling. Therefore, initial categories for the codes were based on aspects of model use by experts as described in Quillin and Thomas (2015), which was discussed in Chapter Two for the conceptual framework. Quillin and Thomas (2015) defined seven different modeling aspects for drawing-to-reason based on their literature review of drawing, which included (a) model relationship to reality, (b) model relationship to other models, (c) flexibility, (d) salient features, (e) purpose, (f) spontaneous use, and (g) metacognition.

In the first step for the matrix structuring, all seven aspects were considered as potential categories with initial definitions and anchoring samples guided by the perceptual inventory of the PSTs’ drawings. The matrix categories were revised through iterative cycles of peer debriefing with the researcher’s advisor to discuss definitions and relevance to the PSTs’ drawings and preliminary coding of the final version of the water-force drawings. The final matrix included three main categories based on model use aspects, which were defined as (a) model relationships, (b) purpose and salient features, and (c) metacognition. The revisions of the categories reflected elimination of the categories for which relevant examples from the drawings could not be identified, including flexibility and spontaneous use. Other revisions were the
combination of categories for which there was overlap in anchoring samples identified from the drawings.

**Figure 3.14**

*Structuring of Matrix for Visual Content Analysis of PSTs’ Drawings Based on Model Aspects*

Note: Schematic of the organization phase, including iterative structuring of the model aspects’ category matrix for deductive content analysis of PSTs’ drawings. Steps that included peer debriefing as a validation check to support trustworthiness of the analysis are indicated with arrows.
The first main category in the matrix for visual content analysis of the PSTs’ drawings based on model aspects was model relationships, which combined both relationships to reality and relationships to other models. As described in Chapter Two, individuals’ ability to use and interpret representational translations are a key component of visual literacy (Quillin & Thomas, 2015). Expert model users represent ideas with both images and text, with different visuals on the same spatial scale, and with visuals on different spatial scales. Therefore, the model relationships category included three generic categories for the distinct types of translations used by the PSTs to represent ideas, including a) visual-text, b) horizontal, and c) vertical (Figure 3.15).

**Figure 3.15**

*Operationalized Measures for Model Relationships in PST Drawings*

<table>
<thead>
<tr>
<th>Main Category</th>
<th>Generic Categories</th>
<th>Sub-categories</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Model Relationships</strong></td>
<td>Visual ↔ Text Translations</td>
<td>Conceptual Processes</td>
</tr>
<tr>
<td>An aspect of model use that refers to individuals’ understanding of representational correspondence between a model and reality or among multiple models (Quillin and Thomas, 2015)</td>
<td>Horizontal Translations</td>
<td>Physical Properties</td>
</tr>
<tr>
<td></td>
<td>Vertical Translations</td>
<td>Spatial Properties</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Structural Properties</td>
</tr>
</tbody>
</table>

To further differentiate the vertical translation category, it was subcategorized into PSTs’ use to depict (a) processes (e.g. cohesion between water molecules), (b) physical properties (e.g. charge distribution in water molecules), (c) spatial information (e.g., density of molecules in liquids versus solids), and (d) structural information (e.g., the molecular structure of water). A schematic of the model relationship category, which includes its definition and associated
generic categories and subcategories is shown in Figure 3.15. The deductive content analysis of the drawings for model relationships was used to count the existence of the different categories of translations in the Cartesian diver drawing and in the different versions of the water-force phenomenon drawings. Based on model relationships, evidence for PSTs’ more expert drawing-to-reason was inclusion of more types of translations with subsequent drawings.

The next main category combined the model use aspects of purpose and salient features from Quillin and Thomas (2015). These aspects focus on individuals’ view of the purpose for drawing and the salience of the included visual elements for an explanation of the science phenomenon. Drawing-to-reason is a process-oriented purpose for drawing (Ainsworth, 2011; Quillin & Thomas, 2015) in which individuals use drawings as a thinking tool to reason about a phenomenon and include non-observable structures, processes, and relationships as part of their drawn explanation. More product-oriented purposes of drawing, such as drawing-to-learn, focus on depiction and labeling of observable features for a phenomenon and conveyance of canonical science concepts considered to be correct explanations. Therefore, the main category of purpose and salient features was structured to include three generic categories that could be used to interpret the PSTs’ purpose for drawing during the series of lessons and the type of features they included in their drawings. The three generic categories were (a) foundational images and scale tools, (b) text, and (c) features, (Figure 3.16). Each of the three generic categories were divided into additional subcategories for coding the drawings as described in more detail below.
Figure 3.16

Operationalized Measures for Salient Features and Purposes in PST Drawings

The first generic category for purpose and salient features was foundational images and scale tools, which included subcategories for the different graphic symbols (Figure 3.4) that were introduced as part of the visual literacy instructional interventions. These graphic symbols were intended to support PSTs’ inclusion of more salient features in their drawings to explain how and why the phenomenon occurred versus recording what they observed. The subcategories for vectors and the magnification tool were further differentiated based on how the PSTs used them as visual representations in their drawings. Vectors were coded based on whether they represented force, direction, or magnitude in the PSTs’ drawings. Inclusion of the magnification tool was coded based on its purpose to depict non-observable structures versus non-observable processes. For the visual content analysis, the Cartesian diver drawing, and each version of the water-force phenomenon drawings were coded for the existence of each subtype of foundational image and scale tool. Evidence of PSTs’ more expert drawing-to-reason was inclusion of more examples of different foundational images and scale tools in subsequent drawings. Evidence of a
more process-oriented purpose for drawing was PSTs’ inclusion of more non-observable structures, processes, and relationships relative to observable features in subsequent drawings.

The next generic category for purpose and salient features was text, which was subcategorized by the purpose of the textual representations either for (a) labeling of visual representations or (b) explanation to support the visual representations in PST-generated drawings. Textual representations for labeling were considered consistent with more product-oriented purposes for drawings, while text for explanation was considered consistent with more process-oriented purposes. During coding, the unit of analysis for text purpose was the whole textual representation for the conveyed idea, which could include single words, short phrases, or complete sentences. For example, an individual incidence of a textual representation from the drawings included the word “water”, the phrase “washcloth in space”, and the sentence “The hands applied a squeezing force to the washcloth.” In the examples, “water” and “washcloth in space” were coded as text use for labeling, while “The hands applied a squeezing force to the washcloth” was coded as text use for explanation. For the content analysis, the frequency of text for labeling versus explanation in the Cartesian diver drawing and the four versions of the water-force phenomenon drawings were used to support interpretation of PSTs’ purpose for drawing during the series of lessons with explicit instruction on drawing-to-reason. Evidence of a more process-oriented purpose for drawing was PSTs’ inclusion of more text for explanations versus labeling in subsequent drawings.

Features was the last generic category under purpose and salient features, which was used to differentiate the visual representations depicted in the PSTs’ drawings based on their saliency for an explanation of the phenomenon. Inclusion of mainly observable features was considered to be consistent with a more product-oriented purpose for drawing, while inclusion of non-
observable structures, processes and relationships was considered more process-oriented. The structuring of the matrix categories for non-observable structures, processes, and relationships was described in the section for the content analysis of intermolecular water force knowledge. The categories for the observable features were based on the perceptual inventory of the PSTs’ drawings (see Appendix E). The final matrix with categories used to code for observable features in the PSTs’ drawings and written explanations is listed in Table 3.12.

Table 3.12
Matrix for Observable Features Coded in Drawings and Written Explanations

<table>
<thead>
<tr>
<th>Categories</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water or Water droplets</td>
<td>Any drawn or textual representation of a volume of water including drops falling from cloth on earth or suspended droplets in space</td>
</tr>
<tr>
<td>Water layer</td>
<td>Drawn or textual representation of the layer of water around the washcloth or perceived wetness of the washcloth on earth or in space</td>
</tr>
<tr>
<td>Astronaut</td>
<td>Drawn or textual representation of the astronaut in space</td>
</tr>
<tr>
<td>Twisting from hands</td>
<td>Drawn or textual representation of hands twisting the washcloth including vectors if used just to indicate the direction of twisting (excludes vectors indicating twist as a compression force)</td>
</tr>
<tr>
<td>Washcloth</td>
<td>Drawn or textual representation of the physical washcloth on earth or in space</td>
</tr>
<tr>
<td>Falling</td>
<td>Drawn vectors or text to describe the downward trajectory of water droplets falling.</td>
</tr>
<tr>
<td>Earth</td>
<td>Drawn or textual representation to depict the planet earth</td>
</tr>
<tr>
<td>Space</td>
<td>Drawn or textual representation to depict a physical location outside of the earth’s atmosphere</td>
</tr>
</tbody>
</table>
During the deductive content analysis, all the representations in the drawings were coded as either an observable feature or non-observable structure, process, and relationship. However, only unique examples for each of the generic categories in the observable features’ matrix (Table 3.12) or in non-observable structures, processes, and relationships’ matrix (Table 3.11) were counted in each of the four versions of the water-force phenomenon drawings. Duplicate examples that were coded for the different generic categories in the matrices were counted as a single existence for that version of the drawing. Evidence of a more process-oriented purpose for drawing was PSTs’ inclusion of more non-observable structures, processes, and relationships relative to observable features in subsequent drawings.

The Cartesian diver drawing also was coded for the frequency of observable features versus non-observable structures, processes, and relationships, but was not compared with the water-force phenomenon. It was used as an explore their prior knowledge about drawing-to-reason.

The final main category in the matrix for the visual content analysis of the PSTs’ drawings based on model aspects was metacognition, which explored PSTs’ awareness of the quality of their drawings based on the included science ideas and their uncertainties about their understanding of the phenomenon. A schematic of metacognition and the generic categories for the type of revisions the PSTs included in each version of their water-force drawings is shown in Figure 3.17. PSTs’ revisions were categorized as (a) content revisions to incorporate science ideas from lessons (see Table 3.2 for lesson activities), (b) prompted responses to instructor’s comments, or (c) questions the PSTs still wondered about the water-force phenomenon. The cumulative number of each revision type over time was used as the measure for metacognition. For example, a PST response to a prompt in the second drawing continued to be counted as an
incidence of a revision in the third and fourth drawings. Based on metacognition, evidence for PSTs’ more expert drawing-to-reason was inclusion of more revisions, prompted responses, or indications of questions with subsequent drawings.

**Figure 3.17**

*Operationalized Measures for Metacognition from PST Drawings*

The deductive content analysis of the drawings was implemented in a sequence based on the three main categories in the matrix (Figure 3.18). All drawings for each PST subunit, including the Cartesian diver and the series of four drawings for the water-force phenomenon, were coded first for model relationships. The next phase for the final coding of all the PSTs’ drawings was the purpose and salient features, which was coded in phases for the foundational images and scale tools, text purpose, and features. The last coded phase was the metacognition category. For the metacognition category, the coding scheme only included the water-force phenomenon drawings because the PSTs did not revise their Cartesian diver drawings. As shown in Figure 3.14, a peer debriefing with the researcher’s advisor to review all PSTs’ drawings with the final coding for the three categories and interpretation of the analysis was conducted as part of the organization phase for the visual content analysis.
Figure 3.18

**Coding Scheme for Visual Content Analysis of PSTs’ Drawings Based on Model Aspects**

---

**Step One: Code for Model Relationships**
Mark *one* example per translation based on type:
- Visual → Text (VT)
- Horizontal (↔)
- Vertical for conceptual processes (↑p), physical properties (↑+), spatial properties (↑sp), structural properties (↑st)

---

**Step Two: Code for Purpose and Salient Features**

**Foundational Images and Scale Tools**
Mark *one* example per type:
- Vectors for force (Vf), direction (Vd), or magnitude (Vm)
- Frames
- Magnification tool for feature (Ms) or process (Mp)
- Particle Model

**Text Purpose**
Mark *all* text examples based on use:
- Label for observable and non-observable features (L)
- Explanation of or textual addition to drawn ideas (E)

**Features**
Mark all examples of observable features and non-observable structures, processes, and relationships in drawings:
- Count *one* example per distinct *observable* features in Table 3.12
- Count *one* example per distinct *non-observable* structures, processes, and relationships in Table 3.11

---

**Step Three: Code for Metacognition**
Mark *all* revisions in updated drawings based on category:
- Revisions based on lesson content (R)
- Revisions prompted by instructor feedback on drawings (P)
- Questions posed by PSTS about things they still wonder or are uncertain (Q)
The final coding scheme, including the indexical symbols used to correspond with the different categories, generic categories and subcategories, is provided in Table 3.13. Figures 3.19 to 3.23 are examples of all coded drawings from Reece, one of the PSTs participating in the study.

Table 3.13

*Final Category Matrix for Content Analysis of PSTs’ Drawings Based on Model Aspects*

<table>
<thead>
<tr>
<th>Coding Symbol</th>
<th>Generic Category</th>
<th>Subcategory</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Main Category: Model Relationships</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VT</td>
<td>Visual ↔ Text Translations</td>
<td></td>
<td>Depiction of a structure, process, or relationship as both visual and textual representations</td>
</tr>
<tr>
<td>←→</td>
<td>Horizontal Translations</td>
<td></td>
<td>Different visual representations of a structure or process on the same scale</td>
</tr>
<tr>
<td>↑p</td>
<td>Vertical translations</td>
<td>Conceptual process</td>
<td>Different visual representations of a process on different scales</td>
</tr>
<tr>
<td>↑+</td>
<td>Vertical translations</td>
<td>Physical properties</td>
<td>Different visual representations of a structure on different scales to depict physical properties</td>
</tr>
<tr>
<td>↑sp</td>
<td>Vertical translations</td>
<td>Spatial properties</td>
<td>Different visual representations of a structure on different scales to depict spatial properties</td>
</tr>
<tr>
<td>↑st</td>
<td>Vertical translations</td>
<td>Structural properties</td>
<td>Different visual representations of a structure on different scales to depict composition, arrangement, or organization</td>
</tr>
</tbody>
</table>
Table 3.13 (continued)

<table>
<thead>
<tr>
<th>Coding Symbol</th>
<th>Generic Category</th>
<th>Subcategory</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>Foundational images &amp; scale tools</td>
<td>Frame</td>
<td>Scale tool to represent a comparison, sequence, progression, or series among ideas</td>
</tr>
<tr>
<td>M_s</td>
<td>Foundational images &amp; scale tools</td>
<td>Magnification tool for structures</td>
<td>Scale tool to represent enlarging the geometric scale of a non-observable structure</td>
</tr>
<tr>
<td>M_p</td>
<td>Foundational images &amp; scale tools</td>
<td>Magnification tool for processes</td>
<td>Scale tool to represent enlarging the geometric scale of a non-observable process</td>
</tr>
<tr>
<td>P</td>
<td>Foundational images &amp; scale tools</td>
<td>Particle model</td>
<td>Foundational image to represent non-observable parts of matter that make up observable forms of matter</td>
</tr>
<tr>
<td>V_d</td>
<td>Foundational images &amp; scale tools</td>
<td>Direction vector</td>
<td>Foundational image in the form of an arrow to represent the direction of motion</td>
</tr>
<tr>
<td>V_f</td>
<td>Foundational images &amp; scale tools</td>
<td>Force vector</td>
<td>Foundational image in the form of an arrow to represent the process of force</td>
</tr>
<tr>
<td>V_m</td>
<td>Foundational images &amp; scale tools</td>
<td>Magnitude vector</td>
<td>Foundational image in the form of an arrow to represent the magnitude of a non-observable structure or process</td>
</tr>
<tr>
<td>L</td>
<td>Text</td>
<td>For labeling</td>
<td>Textual representations that are used label drawn images</td>
</tr>
<tr>
<td>E</td>
<td>Text</td>
<td>For explanation</td>
<td>Textual representations that are used to clarify or expand on drawn ideas</td>
</tr>
<tr>
<td></td>
<td>Features</td>
<td>Observable Features</td>
<td>Descriptive but not explanatory features of science phenomena, which are visible to the unaided eye</td>
</tr>
<tr>
<td></td>
<td>Features</td>
<td>Non-observable structure, process, or relationship</td>
<td>Explanatory features of science phenomena, such as the composition, spatial arrangement/organization, or physical properties of material objects and non-material processes, systems, or patterns</td>
</tr>
</tbody>
</table>
Table 3.13 (continued)

<table>
<thead>
<tr>
<th>Coding Symbol</th>
<th>Generic Category</th>
<th>Subcategory</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>R</td>
<td>Content</td>
<td>revisions</td>
<td>PST revisions to drawings to incorporate lesson content after evaluating prior version of drawing</td>
</tr>
<tr>
<td>P</td>
<td>Prompted</td>
<td>responses</td>
<td>Prompted revisions in response to instructor feedback</td>
</tr>
<tr>
<td>Q</td>
<td>Questions</td>
<td></td>
<td>Lingering questions that PSTs still wonder about the explanation for the phenomenon</td>
</tr>
</tbody>
</table>

*Main Category: Metacognition*

*Note:* Red arrows on drawings in Figures 3.19 to 3.23 were used to code alternate conceptions that PSTs included in their drawings for the water-force phenomenon. They were not used as operationalized measures for the PSTs’ SK knowledge regarding drawing as a science practice, and therefore, are not included in the table that summarizes the category matrix used in the visual content analysis of the drawings.
Figure 3.19

Example of Reece’s Cartesian Diver Drawing with Codes
Figure 3.20

Example of Reece’s First Water-Force Drawing with Codes
Figure 3.21

Example of Reece’s Second Water-Force Drawing with Codes
Figure 3.22

Example of Reece’s Third Water-Force Drawing with Codes
Figure 3.23

Example of Reece’s Final Water-Force Drawing with Codes
Semi-structured Interviews. PSTs’ responses in the semi-structured interviews were analyzed by a content analysis (Elo & Kyngäs, 2007) with a deductive approach. The purpose of the content analysis was to triangulate the findings from the PST-generated drawings with their own discussion of the series of drawings, including their new knowledge about force-related ideas or the practice of drawing based on model aspects. The matrix for the deductive coding of the interviews based on the main categories of science ideas and drawing as a practice are listed in Table 3.14. The main category of science ideas included generic categories for prior force-related knowledge and new force-related knowledge. The main category for drawing as a science practice included generic categories for the three model aspects used for the drawings, which were also subcategorized based on prior versus new knowledge. Their responses for differentiated based on reference to prior to and after the science methods course to determine what the PSTs considered new knowledge.

Table 3.14

<table>
<thead>
<tr>
<th>Category Matrix for Content Analysis of Interviews for SK Learning Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Generic Category</strong></td>
</tr>
<tr>
<td>----------------------</td>
</tr>
<tr>
<td><strong>Main Category: Science ideas</strong></td>
</tr>
<tr>
<td>Prior Force-related Knowledge</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>New Force-related Knowledge</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Generic Category</td>
</tr>
<tr>
<td>------------------</td>
</tr>
<tr>
<td><strong>Main Category: Drawing as a science practice</strong></td>
</tr>
<tr>
<td>Model Relationships</td>
</tr>
<tr>
<td>Model Relationships</td>
</tr>
<tr>
<td>Purpose and Salient Features</td>
</tr>
<tr>
<td>Purpose and Salient Features</td>
</tr>
<tr>
<td>Metacognition</td>
</tr>
<tr>
<td>Metacognition</td>
</tr>
</tbody>
</table>
Sub-question Three

Sub-question three qualitatively explored PCK learning outcomes regarding drawing as an instructional strategy for elementary science after explicit instruction on drawing-to-reason. Primary data (Figure 3.24) for the qualitative analysis included PSTs’ science lesson plans for their field experiences and interview responses regarding the lesson plans, the actual lesson facilitation, and science teaching in general.

Figure 3.24

Qualitative Data Strands to Address Sub-Question Three

Note: Qualitative (QUAL) data were analyzed and synthesized to provide descriptions for the embedded subunits (i.e. the individual PSTs). The subunit descriptions were integrated for an overall case understanding of PSTs’ PCK learning outcomes.
The lesson plans and interview responses were deductively coded based on how the PSTs’ inclusion of drawing in their field experience lessons would support their students’ model use based on the aspects of model relationships, model purpose and salient features, and metacognition (Quillin & Thomas, 2015). These were the same model aspects used to evaluate the PSTs’ drawings and interviews for their SK knowledge about drawing as a science practice. Findings from the deductive content analysis of the lesson plans were triangulated with the deductive content analysis of the interviews to create a synthesized interpretation for each PST subunit. The synthesized interpretations for each subunit were used for an overall case interpretation of PCK learning outcomes regarding drawing as a science instructional strategy after participating in the science methods course with explicit instruction on drawing-to-reason.

The process for the deductive content analysis of the PSTs’ lesson plans and interviews was similar to the process described for sub-questions one and two. See Figure 3.9 for overview of the three phases of the deductive content analysis process based on Elo and Kyngäs (2007). During the preparation phase, the units of analysis for sub-question three were specified as each individual lesson plan for the field and the PSTs’ interviews. To become immersed in the data, all lesson plans and interviews were reviewed to gain familiarity with their content prior to structuring the category matrix for deductive coding.

The structuring process for the category matrix used to analyze the lesson plans and interviews based on model use aspects from Quillin and Thomas (2015) was similar to the process described for analyzing the SK learning outcomes for the PSTs. See Figure 3.25 for a schematic of the structuring process during the organization phase for the content analysis.
Figure 3.25

*Structuring Process for Category Matrix for Analysis of PSTs’ Lesson Plans and Interviews*

**Note:** Schematic of structuring the category matrix during the organization phase for the deductive content analysis of the PSTs’ lesson plans based on model aspects. The final matrix was an interative process of defining categories and comparing with the text in the lesson plans and interviews. Steps that included peer debriefing as a validation check to support trustworthiness of the analysis are indicated with arrows.
As discussed for the SK learning outcomes, the goal of the explicit instruction on drawing-to-reason was to help PSTs learn how to incorporate drawing in their own instruction for more process-oriented purposes such as drawing-to-reason, which is a form of science modeling. Therefore, model use aspects of model relationships, purpose and salient features, and metacognition were used as the main categories for the content analysis. In addition, the main category of timing was used for differentiating the lesson plans or responses in the interviews based on whether the referenced instruction occurred prior to or after the series of lessons with explicit instruction on drawing-to-reason. Generic categories were included for each main category to differentiate between the PSTs’ incorporation of drawing in their lessons that would support students novice model use versus more expert model use of drawing. Initial definitions and anchoring samples were based on the review of the data artifacts during the preparation phase. The rest of the organization phase for analysis of the lesson plans and the interviews are described in more detail in the following sections.

**Science Lesson Plans.** The category matrix was finalized through an iterative cycle of comparing initial categories with one PSTs’ lesson plan to determine it would be adequate for interpreting how drawings were incorporated in lessons and if examples could be identified for the different categories. The finalized category matrix with examples from the lesson plans is provided in Table 3.15. The final matrix was used to code both lesson plans from all four PSTs for the existence of the different categories. Correspondence of the timing category with the novice use versus more expert use in each main category was used to interpret if PSTs incorporated drawing in ways that supported more expert model use by their students after explicit instruction on drawing-to-reason during the science methods course.
Table 3.15

*Category Matrix for Content Analysis of Lesson Plans for PCK Learning Outcomes*

<table>
<thead>
<tr>
<th>Generic Category</th>
<th>Definition</th>
<th>Examples from Lesson Plans</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Main Category: Model Relationships</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| Novice Use       | Did not include drawing or included drawing in way that would lead students to assume a one-to-one relationship between model and reality or not support translation among models | - No drawing in lesson plan  
- Single drawing in plan not connected with other representations or discussion |
| More Expert Use  | Included drawing to support students’ understanding that no model is wholly “right.” Provided opportunities that would support students learning to translate among models | Planned instruction included multiple ways for students to represent phenomenon or ideas such as:  
- Discussion in relation to drawings  
- Written and drawn explanations  
- Drawings of various aspects of the phenomenon (e.g., before, during, after)  
- Sharing of different students' drawings |
| **Main Category: Purpose and Salient Features** | | |
| Novice Use       | Included drawings focused mainly on visible observations, labels for images, or students’ correct answers. The included drawing was more of a final product versus a tool for students to think with. | Drawing in lesson plan focused on:  
- Visible observations  
- Labels for images  
- Correct answers |
| More Expert Use  | Include drawing to support students using them as thinking tools that change. Encouraged students to focus on underlying non-observable structures, processes, and relationships | Included drawing focused on:  
- Student thinking or explanation  
- Non-observable structures, processes, and relationships  
- Multiple answers  
Drawing “process” with student revisions |
Table 3.15 (continued)

<table>
<thead>
<tr>
<th>Generic Category</th>
<th>Definition</th>
<th>Examples from Lesson Plans</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Main Category: Metacognition</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Novice Use</td>
<td>Did not include instruction to support students’ ability to evaluate quality or utility of own models</td>
<td>Instruction plan did not include:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Visual literacy instruction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Prompts to elicit student thinking about drawings</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Opportunities to revise drawings during lesson</td>
</tr>
<tr>
<td>More Expert Use</td>
<td>Included instruction to support students’ ability to evaluate quality or utility of their drawings.</td>
<td>Planned instruction included at least one of the following:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Visual literacy instruction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Prompts to elicit student thinking about drawings</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Opportunities to revise drawings during lesson</td>
</tr>
<tr>
<td><strong>Category: Timing</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prior to Instruction</td>
<td>Created plans prior to all five weeks of lessons on explicit instruction on drawing to reason.</td>
<td>Examples in first field experience lesson plan</td>
</tr>
<tr>
<td>After Instruction</td>
<td>Created plans after all five weeks of lessons on explicit instruction on drawing to reason</td>
<td>Examples in second field experience lesson plan</td>
</tr>
</tbody>
</table>
**Semi-structured Interviews.** The category matrix was finalized through an iterative cycle of comparing initial categories with one PSTs’ interview to determine it would be adequate for interpreting how drawings were incorporated in lessons and if examples could be identified for the different categories. An additional main category that was added during the iterative process of structuring the matrix was explicit instructional interventions with generic categories for the affective characteristics, visual literacy, and modeling interventions. This was used to code specific examples from the explicit instruction that PSTs discussed using in their own instruction.

The finalized category matrix with examples from the interviews is provided in Table 3.16. The final matrix was used to code interviews from all four PSTs for the existence of the different categories. Correspondence of the timing category with the novice use versus more expert use in each main category was used to interpret if PSTs incorporated drawing in ways that supported more expert model use by their students after explicit instruction on drawing-to-reason during the science methods course. The PSTs’ interview responses also were used to triangulate with the lesson plans to verify that what was included in the plan was implemented with the students during the facilitation of the actual lesson.
### Table 3.16

*Category Matrix for Content Analysis of Interviews for PCK Learning Outcomes*

<table>
<thead>
<tr>
<th>Generic Categories</th>
<th>Definition</th>
<th>Example from Interviews</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Main Category: Model Relationships</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Novice Use</td>
<td>Did not mention drawing or included drawing in way that would lead students to assume a one-to-one relationship between model and reality or not support translation among models</td>
<td>No mention of drawing with students for first or second lesson</td>
</tr>
<tr>
<td>More Expert Use</td>
<td>Discussed including multiple ways for students to represent phenomenon or ideas, including small group and whole discussion about different drawings</td>
<td>[Reece] “We had students discuss [their drawings] in their groups and they presented their ideas to the class just verbally</td>
</tr>
</tbody>
</table>
### Table 3.16 (continued)

<table>
<thead>
<tr>
<th>Generic Categories</th>
<th>Definition</th>
<th>Example from Interviews</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Main Category: Purpose &amp; Salient Features</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Novice Use</td>
<td>Discussed inclusion of drawing focused mainly on visible observations, labels for images, or students’ correct answers. The included drawing was more of a final product versus a tool for students to think with.</td>
<td>[Joan] “So we went over how to make an observation and that was discussion. I asked them like, &quot;What is an observation? How do you make an observation?&quot;</td>
</tr>
<tr>
<td>More Expert Use</td>
<td>Discussed drawing as a process versus as a final product. For example, encouraged students to explain their thinking in drawings and the inclusion of prompts for non-observable structures, processes, and relationships, and allowed multiple answers versus a correct response.</td>
<td></td>
</tr>
<tr>
<td><strong>Main Category: Metacognition</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Novice Use</td>
<td>Did not discuss inclusion of visual literacy instruction, prompts to elicit student thinking about drawings, or opportunities to revise drawings.</td>
<td>[Joan] “I kind of just let them do it on their own.”</td>
</tr>
<tr>
<td>More Expert Use</td>
<td>Discussed inclusion of visual literacy instruction to help students with their quality of drawing, prompts to elicit student thinking about drawings, or opportunities to revise drawings.</td>
<td>[Reece] “by doing a small drawing of how they might show forces to indicate direction and possibly show them how to draw a magnification so they can understand what is happening in the canister.”</td>
</tr>
</tbody>
</table>
Table 3.16 (continued)

<table>
<thead>
<tr>
<th>Generic Categories</th>
<th>Definition</th>
<th>Example from Interviews</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Main Category: Timing</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prior to Instruction</td>
<td>Responses related to first field experience lesson with Page Keeley probe.</td>
<td>Examples in first field experience lesson plan</td>
</tr>
<tr>
<td>After Instruction</td>
<td>Responses related to second field experience lesson with discrepant event.</td>
<td>Examples in second field experience lesson plan</td>
</tr>
<tr>
<td><strong>Main Category: Explicit Instruction Interventions</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Affective Characteristics</td>
<td>Any reference to interventions such as positive feedback and encouragement, comments indicating value or interest</td>
<td>[Joan] “…That came from what we were doing in class, and I wanted to apply it to the lesson.”</td>
</tr>
<tr>
<td>Visual Literacy</td>
<td>Any reference to the foundational images and scale tools, instructor modeling drawing, or learning to draw during the course</td>
<td>[Joan] “…And the worksheet had a before, during and after section so that they could see the change drawn out.”</td>
</tr>
<tr>
<td>Modeling</td>
<td>Any reference to the iterative cycle of create, evaluate and revise</td>
<td>[Eileen] &quot;If we had given them more time to revise their drawings. Granted, it isn't our class, so we couldn't really take that time to have it be a multiple day lesson. But I think their drawings could have been even better too, with that”</td>
</tr>
</tbody>
</table>
Trustworthiness

The trustworthiness of a study addresses the credibility of a researcher’s findings and their interpretation of the data. Lincoln and Guba (1986) outlined a series of four criteria for interpretivist studies, which are analogous to evaluative measures such as internal validity, external validity, reliability and objectivity used in quantitive studies that are positivist. Their criteria are based on axioms for naturalistic research, which include the recognition of multiple, socially constructed realities; context-specific findings; holistic explanations with multiple, interacting factors to capture the nature of the studied phenomena, influential researcher and participant relationships, and the presence of values in all research endeavors. Their four criteria for trustworthiness include credibility, transferability, dependability, and confirmability. The sections below outline how each of the criteria were addressed in this research study.

Credibility

Credibility addresses the issue of whether the researcher’s interpretation of the data collected for a studied phenomenon is an accurate representation of reality from the perspective of the participant. For this study, it provides a way for the reader to trust that the researcher’s findings accurately reflect the participants’ experiences and ideas during the science methods course with explicit instruction on drawing-to-reason. While the question of how accurately an interpretation aligns with reality is subjective, Lincoln and Guba (1986) outlined several techniques that can be used to support the credibility of an interpretivist study. Their outlined techniques incorporated in this research study included a) prolonged engagement, b) triangulation, c) peer debriefing, and d) member checks.

Prolonged engagement refers to having extensive and meaningful interactions with research participants, which builds trust between the researcher and participants, provides greater
familiarity of the participants and the study context, and allows for richer, thicker descriptions of the collected data. In this study, the researcher was the PSTs’ instructor for the science methods course during all 14 weeks of the spring semester. In addition, the researcher had an existing relationship with each of the participants as their instructor for their engineering methods course during the prior fall semester. Having the role of the instructor with the PSTs for two semesters, provided the opportunity to observe and become more familiar with their characteristics as individual learners and to build a supportive and trustful relationship in which they felt safe to share their ideas.

As their instructor in the engineering and science methods courses, the researcher was intentional with actions taken both within the classroom environment, as well as outside the class meeting time, to build supportive and trusting relationships with the PSTs. For example, during both the engineering methods course and the science methods course, the researcher met with the students three times over the course of the semester (beginning, midway, and at the end of the semester) to discuss both their progress and concerns about their coursework, as well as to learn about their interests, activities, and life goals. The initial weeks in both methods courses were spent building relationships among the students, as well as with the instructor. The fall engineering course incorporated the Storybird app (Storybird, n.d.) for the PSTs to create and share picture books about their STEM educational experiences. Other activities that were used to build relationships and learn about the PSTs included use of Climer Card activities (Climercards, 2023), Padlet posts about their personal backgrounds and interests to share with the class, and makerspace projects that involved sharing their interests and backgrounds. The researcher as the instructor also shared her background and interests with the students, and when possible, attended or watched extracurricular events in which the PSTs were involved.
Throughout the semester for both the engineering and science methods courses, the researcher as the instructor sent weekly emails to the PSTs, which were called “Friday Forwards.” The emails included upcoming assignments, the upcoming class’s agenda, and additional fun or interesting news. The additional information often targeted the students’ socioemotional health and included clips from Brené Brown, inspirational quotes from Mister Rogers, or guidance from online teaching resources, such as Edutopia. For the courses’ activities and assignments, the researcher as the instructor provided supplies to help defray costs and reduce time demands on the PSTs.

Triangulation was another credibility technique recommended by Lincoln and Guba (1986), which was incorporated in this study through both the use of different data methods and different data sources. The convergent design for this mixed methods study used both qualitative and quantitative data strands. The study followed strategies recommended by Creswell and Plano-Clark (2018) such as using data from several sources as outlined in Table 3.6 for each of the three subquestions. In addition, the research design incorporated four subunits so that evidence for the coding and interpretation of the overall case was based on data from multiple individuals.

Peer debriefing was also incorporated as a credibility technique throughout the study. As outlined in the Data Analysis sections for each subquestion, peer debriefing steps with the researcher’s advisor were included in several steps during the structuring of the matrices for the deductive coding of data artefacts, as well as after final coding. In addition, a fellow doctoral colleague provided peer debriefing on the conceptual and operationalized definitions of the categories used for deductive coding of affective characteristics and aspects of model use.
The final credibility technique incorporated into the study was member checking. Each PST was provided their subsection of Chapter 4, which summarized the researcher’s interpretation of their learning outcomes during the course based on the analysis of their data artefacts. All four PSTs reviewed and provided affirmation that the researcher’s interpretation of their experiences and learning during the science methods course were accurate and did not have requested changes or additional information to add.

**Transferability**

Transferability, not replicability, is the goal of interpretivist studies, since the findings are context-based, but can offer insights to other scenarios. The ability to transfer findings to other applicable situations requires full and substantial details about the context and participants. In this study, transferability was addressed by providing a thick description of the PST participants, the teacher education program in which the PSTs were enrolled, the science methods course structure and content, the lessons with explicit instruction on drawing-to-reason, the PSTs’ field experiences, and timeline of study activities and data collection throughout the course.

**Dependability**

Dependability establishes trust in the process by which a study was designed and executed, so that if it was repeated by the researcher with the same participants and data, the findings would be consistent. As stated by Lincoln and Guba (1985), “Would the findings of an inquiry be repeated if it were replicated with the same or similar participants in the same context” (Elo et al., 2014, p. 4). Dependability techniques allow readers to discern if the methodology was rigorous and therefore, the researcher’s findings can be relied on. In this research, dependability was addressed in several ways. Although an external audit of the research was not performed, the first dependability technique incorporated in the research was
establishment of an audit trail for the research. Stahl and King (2020) referred to the practice of bracketing raw data from researchers’ interpretations during collection, analysis and reporting as a reflexive technique undertaken in anticipation of an independent review of the work by a peer. For this study, Yin’s (2009) guidance for case study documentation and organization was used for data collection, analysis, and reporting. An electronic study database was created on the researcher’s NC State google drive and organized based on raw data artefacts, data assessment documentation, and reports of findings. The researcher maintained logs on the data analysis process of in a google document and researcher notebook, as well as generated do files for analysis steps and recorded log files for all quantitative analysis on Stata. Another dependability technique was the inclusion of extensive details about the data collection and data analysis processes, particularly those for the deductive content analysis of the interviews, lesson plans and PST-generated drawings in the chapter on methodology. The use of both detailed text and diagrams to convey the details of all three phases of the content analysis process was based on guidance from Elo et al. (2014) and their checklist for improving the trustworthiness of content analysis in a study. Finally, while not as rigorous as a external co-coder with inter-rater reliability, peer debriefings, as described for the credibility criteria, also served as a source for dependability. After completion of the deductive content analysis of data artefacts, the coded drawings and examples from interviews and lesson plans were shared and discussed with the researcher’s advisor as a check for representativeness of matrix categories.

**Confirmability**

Confirmability addresses trust that the findings from the study could have been generated by a different researcher and are not due solely to the biases of the researcher. This criteria was addressed in the study by providing extensive details on the matrices used for the deductive
content analysis, including both the conceptual and operationalized definitions, along with representative examples from the data artefacts. Images of the coded drawings were also provided for transparency of how the visual elements of the PSTs were coded based on the final category matrix. In addition, the process of reflexivity was incorporated into the data analysis and reporting of findings for the study. After the data artefacts had been coded based on the deductive content analysis matrices and all data had been synthesized for each PST, the researcher reviewed the coded documents and analysis notes to ensure categories had been applied consistently during the analysis process and the data was represented accurately. In addition, the researcher provided a detailed positionality statement to provide transparency regarding how her values and beliefs may have influenced the study’s design, implementation, and research findings.
CHAPTER 4

FINDINGS

The purpose of this study was to explore four elementary PSTs’ learning outcomes based on affective characteristics, SK, and PCK during a science methods course that incorporated explicit instruction on drawing-to-reason about force-related phenomena. The central research question for this mixed methods study was: What are PSTs’ learning outcomes based on affective characteristics, SK, and PCK from an elementary science methods course that incorporates explicit instruction on drawing-to-reason? This central question was explored via the following sub-questions:

1. How do PSTs’ self-reported affective characteristics towards drawing, physical science, and science teaching change from the beginning to the end of the science methods course with explicit instruction on drawing-to-reason?

2. How do PSTs’ drawings and ideas about force-related phenomena evolve over a series of lessons that include explicit instruction on drawing-to-reason?

3. In what ways do PSTs incorporate drawing as an instructional strategy in their science lessons for field experiences after explicit instruction on drawing-to-reason?

As described in Chapter Three, the research design for this study was a single case study with embedded subunits. According to Scholz and Tietje (2002), case studies with embedded subunits can be envisioned as knowledge layers that build an overall, descriptive picture of the case (Figure 4.1). The first layer of knowledge integration is analysis of the primary qualitative and quantitative data strands, which was described in Chapter Three. The next layer is synthesis.
of the data for each of the embedded subunits, which for this study were the individual PSTs. The final layer integrates the subunits to build an overall understanding for the case.

**Figure 4.1**

*Knowledge Integration for Single Case Study with Embedded Subunits*

*Note.* Diagram representation for knowledge integration in a single case study with embedded subunits based on Scholz and Tietje (2002). In this study, the case being described is an elementary teacher education science methods course that incorporates explicit instruction on drawing-to-reason. The first layer of knowledge integration is analysis of the primary qualitative and quantitative data strands (see Chapter 3). The second layer is synthesis of the data to conceptualize learning outcomes for each of the PST subunits (Chapter 4). The final layer of knowledge integration generates an overall understanding of the case (see Chapter 5).
In this study, the overall case was an elementary science methods course that incorporated a series of lessons with explicit instruction on drawing-to-reason as part of the overall course content for the semester. This case was bounded by a) the focus on learning to facilitate science instruction for grades three to five, b) the researcher serving as the instructor or record for the course, and c) inclusion junior undergraduate students as PSTs in their 1st year of a STEM-focused teacher education program. The PSTs had completed a prior science methods course for instructing science for grades K to one with a different instructor than the researcher. In addition, the PSTs had a prior engineering methods course in which the researcher had served as their instructor of record, and therefore, they had established a teacher-student relationship with the researcher prior to participating in this study. The overall interpretation for this single case, which integrates the results for the four PSTs, is summarized in Chapter Five.

This chapter synthesizes the primary quantitative and qualitative data for the embedded subunits, and therefore, is organized by the individual PSTs. There is a subsection for each PST, which includes a general description for context and a descriptive interpretation of the qualitative and quantitative data strands according to the three research sub-questions. For learning outcomes regarding affective characteristics, results for each PST were based on the SDA and T-STEM instruments and responses from semi-structured interviews (see Appendix F for transcripts) that were coded based on affective constructs outlined in Table 3.10. For SK learning outcomes, results for changes in each PSTs’ conceptual ideas were based on the content analysis of ideas included in their series of drawings as they reasoned about force-related phenomena. Changes in PSTs’ ideas about the intermolecular water-force phenomenon that were based on content analysis of their drawings were triangulated against their discussion and self-reported learning in the semi-structured interviews. For PSTs’ knowledge of science practices (ie how
they used drawing-to-reason for their own learning), results were based on content knowledge of their drawings for the three aspects of model use, including model relationships, purpose and salient features, and metacognition. The operationalized measures for the three different aspects included a) types of translations for model relationships; b) inclusion of foundational images and scale tools, categorization of text use in drawings, and frequency of observable versus non-observable features for purpose and salient features; and c) frequency of types of revisions for metacognition (Figures 3.15 – 3.17; Table 3.13). For PCK learning outcomes (ie how did PSTs use drawing as an instructional strategy), PSTs’ written lesson plans and self-reported lesson facilitation were analyzed based on how the incorporation of drawing would support elementary students’ use of drawing based on the three aspects of model (model relationships, purpose and salient features, and metacognition).

In the subsections below for each PST, there is an initial overview that summarizes their characteristics based on coursework and the researcher’s observations as their instructor. In addition, their science epistemological views based on the Page Keeley (2010) probe “Doing Science”, a description of their lessons for the field experience weeks, the ATLAST Force and Motion assessment results (Horizons Research Inc., 2011), and their drawings generated to explain the force-related phenomena incorporated in the course are presented prior to results based on learning outcomes, since those data sources are relevant to discussion of affective characteristics, SK, and PCK. For the drawings, the Cartesian diver, first water-force and final water-force phenomenon are included, because they best illustrate changes that occurred during the series of lessons with explicit instruction on drawing-to-reason. Results from other data sources that were analyzed to explore learning outcomes are included for each PST based on the sub-questions.
Avery

Organized and detail-oriented are descriptors that come to mind for Avery both as a student and as a future teacher. During in-person class meetings for the science methods course, Avery was an active contributor to class discussions and activities. She was always prepared with assigned readings and coursework. Her class assignments and work for her field experiences reflected best effort and attention to details, and she was always in the 95th percentile of grades awarded for assessed course assignments. In her assigned teaching reflections after the first and second field experience weeks, she was insightful about her lesson preparation and facilitation. She discussed how the familiarity with the 3E template that had been provided (T. Leavens, personal communication, 2022) and her preparation for the lesson allowed her to feel confident in facilitating her first field experience lesson. She recognized both what had gone well and areas for improvement, connected her field practice to course resources, and provided thoughtful ideas for how to improve in the future based on her actions as a teacher, including ideas for how to continue to develop the students’ knowledge. In the semi-structure interview at the end of the semester, Avery shared that she thought students learned best by doing,

I think that students are able to best learn about science by doing. I don't know if that makes sense, but, through hands-on experiences. I think students can watch a video of somebody else doing an experiment, or they can read a passage explaining scientific concepts, but, when they're able to physically do an experiment or see how a scientific idea works, I think that will stick with them, and that they will better be able to learn and build that foundation and build upon different scientific topics …

During the semester, her use of drawing for her own learning and for teaching she tended to focus on accuracy of observations and language and building science vocabulary.
Initial Science Epistemological Beliefs

One of the early activities in the science methods class explored the PSTs’ views about the nature of science with the Page Keeley probe “Doing Science” (Keeley, 2010) during the 2nd week of the course (Table 3.1). This probe explored PSTs’ understanding of the ways that scientists generate knowledge. While the main purpose for the probe was to model the use of formative assessment probes as a science teaching strategy to elicit students’ ideas, the instructor also used it to gain insight into the PSTs’ ideas about how science knowledge is generated. The probe question and the different answer choices from which the PSTs could select are shown in Figure 4.2.

Figure 4.2
“Doing Science” Formative Assessment Probe (Keeley, 2010)

Doing Science

Four students were having a discussion about how scientists do their work. Below is what they said:

“I think scientists just try out different things until something works.”
~Antoine

“I think there is a definite set of steps all scientists follow called the scientific method.”
~Tamara

“I think scientists use different methods depending on their question.”
~Marcos

“I think scientists use different methods but they all involve doing experiments.”
~Erin

Note. This image is adapted from Keeley (2010) and shows the question and answer choices.
The PSTs were asked to select which answer they agreed with most. They also had to discuss both why they most agreed with the student’s answer in the probe, as well as why they disagreed with the other students statements. Avery indicated that she most agreed with Erin, “I think scientists use different methods but they all involve doing experiments”. The reason she agreed with this statement was,

I agree with Erin the most because science encompasses many different subjects and scientists can use different methods for how they do their work. For example, a marine biologist may use different work methods than a chemist. However, both of these scientists ask questions and use experiments to find answers to these questions (Avery, Probe Response, Jan. 24, 2022).

She disagreed with the other statements because she reasoned that scientists are methodical about their work even if they do not use an exact, standardized process and that science knowledge is only generated from experiments.

I disagree with Antonie because because many scientists will use a method to find answers to their questions rather than guessing and checking until something works. I disagree with Tamara because while many scientists follow the scientific method, this is not a set series of steps all scientists have to follow. Lastly, I disagree with Marcos because all scientists solve questions through experiments (Avery, Probe Response, Jan. 24, 2022).

Avery’s ideas that scientists are methodical in their work was consistent with her organized approach to her own work, as well as suggestive of an interpretivist view about the ways that science knowledge is accumulated. However, her epistemological view of the source of
knowledge was more positivist, since she did not recognize a range of inquiry activities through which scientists build knowledge in addition to experimentation.

Field Experience Lessons

For her field experience during the semester, Avery was assigned to a third grade elementary classroom. She selected the Keeley et al. (2007) probe “Darkness at Night” for her lesson for the first field week to be consistent with her mentor teacher’s lessons on the solar system, which is part of the earth science strand in North Carolina’s standard course of study (NCDPI, 2021a). The “Darkness at Night” probe elicited students’ ideas about the cause of day and night patterns on earth and the extent of their knowledge about earth’s rotation around its axis. Based on her teaching reflection and interview responses, her probe choice may also have reflected her higher confidence in her earth science knowledge, since she commented that she “feel[s] a little better about earth and environmental and life sciences compared [to physical science]…for me, physical science is a bit trickier.” In her reflection on leading the probe lesson, she discussed how comfortable she felt in front of her group of students and rarely consulted her planning notes as she facilitated the student discourse. Her attention to detail was also evident in her lesson plan and reflection in which she commented on how her “in-depth lesson plan…allowed [her] to feel assurance in [her] ability.”

For her second week of teaching in the field, she chose a phenomenon based on an experiment “Build a Film Canister Rocket” from the Science Bob website (Science Bob, n.d.a). The phenomenon involved adding water and an alka-setzer tablet to a film canister that had a press-on lid. After the lid was placed on the film canister with the water and alka-setzer tablet, it was inverted on the ground. The gas pressure inside the canister increased as the tablet dissolved, due to generation of carbon dioxide until it exceeded the force sealing the lid to the canister. The
unbalanced forces caused the film canister to launch into the air. This phenomenon is similar to
the unbalanced forces when launching rockets into space, where the upward force of exhaust
produced from the combustion of fuel is greater than the downward force of gravity. For the
lesson with the canister phenomenon and in her reflection, Avery focused more on the the
students’ knowledge of chemical changes and different states of matter, since the solid tablet was
reacting with water to produce carbon dioxide.

**Force and Motion Knowledge**

The ATLAST Force and Motion assessment (Horizons Research Inc., 2011) was used to
classify PSTs’ general background knowledge about force and motion. As discussed in
Chapter 3, based on guidance from Horizons Inc., the instrument was validated to assess groups
of teachers, not necessarily individuals. However, understanding each PST’s relative level of
knowledge about force and motion was useful for interpreting their data regarding learning
outcomes during the semester. While Avery still had room for growth, her level of force and
motion knowledge was consistent with literature on physical science content knowledge of
preservice elementary teachers (Everett et al., 2009), as well as undergraduate students in general
(Bahtaji, 2023). As shown in Figure 4.3, Avery’s correct responses were slightly lower the group
median for both testing occasions, which was comparable to the mean score reported for a group
of middle school inservice teachers used for creating the instrument (Horizons Research Inc.,
2011).

The change in her correct responses from the beginning to end of the semester likely
represented variability between testing occasions, since the reported retest reliability for the
instrument is 0.88. As discussed in Chapter Three, the ATLAST Force and Motion instrument
(Horizons Research Inc., 2011) assesses a range of sub-ideas and types of knowledge, which are
categorized as content knowledge, knowledge use to analyze/diagnose student thinking, and knowledge use for instructional decisions (see Appendix A). Avery selected at least one correct response on all the sub-ideas included in the assessment with the exception of sub-idea E (If an object is moving faster and faster, then there is a net force acting on the object in the same direction as the motion). In addition, she exhibited knowledge in all three category types.

**Figure 4.3**

*Avery’s ATLAST Force and Motion Responses Compared to the PSTs’ Group Median*

*Note.* Avery’s correct responses at the beginning (blue bar) and end of the semester (orange bar) compared with the median for all four PSTs (gray line). Based on the guidelines for use of the ATLAST Force & Motion Teacher Assessment (Horizon Research, Inc, 2011) the specific values are not listed. The bars are plotted with the median line to provide qualitative information for Avery’s general knowledge about force and motion relative to the other PSTs.
Science Drawings of Force-related Phenomena

Avery’s drawings from the semester are shown in Figures 4.4 to 4.6, including her drawing to explain the Cartesian diver phenomenon (Figure 4.4), her first drawing for her water-force phenomenon on the second week of the series of lessons with explicit instruction on drawing-to-reason (Figure 4.5), and her final drawing for the water-force phenomenon (Figure 4.6). The description of the drawings here will mainly focus on qualitative description, and a more detailed analysis based on the coding scheme outlined in the methodology will be presented below for the SK learning outcomes.

As seen in Figure 4.4, Avery separated her Cartesian diver drawing into frames based on a temporal pattern of before, during, and after by dividing the horizontal space into thirds with vertical lines. This reflected the visual literacy instruction in the class lesson prior to the Cartesian diver demonstration, as well as emphasis on how to create temporal frames that were instructor-modeled for the PSTs immediately prior to generating their drawings. Like the other PSTs, her Cartesian diver drawing focused predominantly on the observable features; however, she did include limited non-observable processes to express her initial ideas about the why the diver sank to the bottom of the bottle when squeezed.

In her middle frame, Avery included her observations that the water level had risen to the top of the bottle when squeezed, which coincided with the diver sinking. She was the only PST who noted this in their drawing. In her last frame, she had noticed that the water level returned to its original level, and the diver rose to the top.
Figure 4.4

Avery’s Cartesian diver Drawing
Figure 4.5

Avery’s First Version of Water-Force Phenomenon

**WASHCLOTH ON EARTH**

- Water droplets
- Water molecules
- Gravity pulls the water down
- The washcloth is being rung out in different directions

**WASHCLOTH IN SPACE**

- Layer of water around the washcloth
- No gravitational force so the water stays in place
- Washcloth is still being rung in different directions

? - Why does the water still form a layer around the washcloth?
Where does the water go once the wash cloth is not being rung out?
Figure 4.6

Avery’s Final Version of Water-Force Phenomenon
For non-observable features, the only other foundational image or scale tool that she used in her Cartesian diver drawing was the vector. Curved, upward-directed and downward-directed vectors were used to represent her ideas of increasing and decreasing water pressures. A straight, downward-directed and upward-directed vector was used to represent the diver sinking and rising. Unlike the other PSTs she did not use inward directing arrows to represent the force of the hand pressing on the bottle. She also did not draw the bottle being distorted from hands, which was included in two of the other PSTs’ drawings.

In her first drawing of the water-force phenomenon (Figure 4.5), Avery included more non-observable structures, processes, and relationships along with observable features. Consistent with her Cartesian diver drawing (Figure 4.4), she included framing, but used a spatial comparison of earth versus outer space instead of the temporal framing. She divided the horizontal space in half with a vertical line. The orientation of images in her drawing was horizontal with a focus on the washcloth, which occupied most of the framed horizontal area for the earth and for outer space frames. The washcloth was drawn as an oval shape outlined by multiple squiggly lines, which conveys the physical properties of a soft material being wrung out. Vertically the features included in the drawing occupied approximately the top, two-thirds of the space. Text was included in the drawings to label drawn elements and to provide explanation about the phenomena. In her drawings, the labels, lines, and shapes were drawn with bold, thick lines. The visual differences between Figures 4.5 and 4.6 are due to researcher processing of the photographed images taken of the drawings.

There were a couple of noteworthy differences in Avery’s drawings of the water-force phenomenon (Figures 4.5 & 4.6), compared with the other PSTs. One was Avery’s extensive use of textual representation for ideas versus visual representations. She includes not only scientific
vocabulary, such as cohesion and adhesion, but also a brief definition of the words. Another important attribute of her drawings compared with the other PSTs was the organization and attention to details. Overall, the textual representations were consistent in size, and there is an orderly arrangement of features in the drawings. For example, in her representation of the particle structure of liquid water (Figures 4.5 & 4.6), her individual particle dots are separated with similar spatial distances. One interesting difference in the text was the size difference in the frame title for earth versus space.

Her representations of visible water in her drawings varied and included textual representation and visual representations of a liquid film and tear-shaped droplets. Differences in the water film on the washcloth on earth versus outer space were represented by both visual and textual representations. Although it cannot be seen in the photographed image shown in Figure 4.6, Avery included faint dots and dashes around the inside perimeter of the washcloth on earth and included text to explain that there was a thin water film that could be felt but not seen. In space, she drew a thicker layer with a squiggly line and enclosed water drops in space. She foregrounded her non-observable features by drawing the magnified particle models and water molecules with bolder pencil marking compared with the washcloth and the surrounding water layer. Like her orderly representation of water particles in the magnifier scale tool (Figures 4.5 & 4.6), the water droplets were organized in rows and with similar space separation between each one.

Avery also incorporated more of the foundational images and scale tools (Figure 3.4) in her drawings of the water-force phenomenon (Figures 4.5 & 4.6) compared to her Cartesian diver drawing (Figure 4.4). In the drawings for the water-force phenomenon, vectors were used to represent direction and force. Vector shape and direction represented distinct types and
direction of force, including a curved arrow for compression force from hands and a downward, straight arrow for gravity. She also used an arrow with a textual representation to represent her ideas of where the forces of adhesion and cohesion would be occurring. Other textual representations for labels and explanations were near the visual representations of her ideas, but she did not use a straight line or arrow to tag the image with the text.

She used the magnifier scale tool (Figure 3.4) in her water-force phenomenon drawings, to vertically translate between visible water and its particle composition, between visible water and its molecular structure, and between the particle model for water and the structure of an individual molecule. Her representations for water included the symbolic representation H$_2$O, a particle model from the foundational images (Figure 3.4), and a two-dimensional, stick-and-ball model with the hydrogen and oxygen atoms labeled with both the element symbol and charge.

**Avery’s Learning Outcomes Based on Affective Characteristics**

This section synthesizes the quantitative and qualitative data strands exploring Avery’s affective characteristics during the science methods course with explicit instruction on drawing-to-reason. Note that all quotes in the following sections are from Avery’s semi-structured at the end of the semester (Avery, Interview, May 24, 2022). Because affective characteristics are targetted towards something (Anderson and Bourke, 2000), this section is organized by affective characteristics towards drawing, physical science, and science teaching.

**Drawing.** Overall, Avery expressed more positive affective characteristics towards drawing at the end of the semester compared with the beginning. In her SDA results (Figure 4.7), the largest difference between the beginning and end-or-semester values, was in the attitude factor that Bauer (2008) attributed to anxiety. The scale ratings for the anxiety factor were reversed, therefore the higher percentage of the maximum scale value represents lower anxiety.
regarding drawing. The other factors, intellectual accessibility and interest & utility, and the adjective set, emotional satisfaction, were also more positive, but the difference between testing occasions was not as great as for anxiety. The change in the anxiety factor for the attitude instrument was consistent with comments Avery made during the end-of-semester interview when discussing drawing for her own learning. Of the four PSTs, Avery’s transcribed interview included the most codes related to positive self efficacy regarding drawing. A comment of Avery’s that stood out in her interview regarded her idea about doing her best,

I think one thing is that, by the end of the semester, it was okay to understand this drawing isn't going to be perfect. It's not going to be. I want to be able just to try my best to get my ideas down, which, I think it can be when you think about asking a student to draw a picture of what they observe relating to a science topic. It can be a little bit tricky for someone to be like, "I don't really know how to draw this. I'm not a good artist. I don't know how to make this represent my ideas in a way that looks good," but understanding that it's not quite for the purpose of making this beautiful picture, but rather to be able to visually see those ideas and label pictures and things like that.

In addition to reflecting the instructional interventions from the spring science methods course, it also showed the growth mindset that was emphasized by this researcher as the instructor during the PSTs’ fall engineering methods course. Another example of her growth mindset and lower anxiety associated the instructional interventions targetting modeling with her learning outcomes,

To be able to build upon that idea and go back and add to our drawings, which was something that I really liked that we did because it allowed ... It wasn't just a one time, "Okay, here's a drawing to help get your ideas out." But, it was a way for us to build upon that knowledge and even understand, "Okay, I didn't have maybe the correct idea at first
with this drawing," but, to be able to refer back to that to be able to see how your thinking has changed.

**Figure 4.7**

*Avery’s Attitude Towards Drawing Based on SDA Instrument*

![Graph showing Avery’s attitude towards drawing based on SDA instrument.](image)

*Note.* The values for three factors and the emotional satisfaction set of bipolar adjectives from the SDA instrument (Bauer, 2008) are plotted as a percentage of the maximum scale value for the respective factor. The values for anxiety were reversed so that the percentage of maximum scale is consistent with the factors and represents a more positive attitude.

The smaller increase in the SDA factor attributed to intellectual accessibility may be related to comments that were coded as negative value towards drawing in Avery’s
interview. There were aspects of drawing that she found challenging. As mentioned in the
description of her drawings, unique attributes of Avery’s drawings were her focus on labeling
images and inclusion of scientific vocabulary, which may be related to interview responses of
sometimes finding writing more valuable than drawing. Avery commented that “…specifically
the more scientific vocabulary terms, it would be a bit easier to write out those definitions and
verbally explain it or in writing rather than trying to draw it out”. Her textual representations of
adhesion and cohesion likely reflect her comment, “I would say … the biggest challenge … were
times of not fully understanding a concept and then trying to add that to the drawing but not fully
understanding of how to apply it to adding onto the drawing”.

The increase in the interest & utility factor of the SDA was consistent with Avery’s
discussion of drawing during her semi-structured interview at the end of the semester. Based on
coding of her interview for affective characteristics, the construct that she mentioned most
regarding drawing was positive value. In her interview, she associated the value of drawing with
its role in enabling students to express their ideas and thinking, which allowed the teacher to
know students’ thinking. For example, when discussing her first lesson with the “Darkness at
Night” probe (Keeley et al., 2007), Avery mentioned how much she valued having her students’
drawings after her lessons to be able to look back on and think about their ideas. She stated that
“[she] wanted to emphasize students referring back to drawings and using those drawings to be
able to help represent their ideas”. She also discussed the value of her students’ drawings for her
as as teacher.

I enjoyed looking back after both of the lessons for redirect week one and two, being able
to collect those worksheets to be able to see students understanding and just being able to
understand their thinking. Time-wise, I wasn't able to ask every student to explain their
thinking and verbally explain to see their understanding, so it was good to be able to have those drawings to get a better understanding of what students know.

Therefore, Avery valued the drawings as a tool for student communication.

**Physical science.** Of the four PSTs, Avery exhibited the least positive affective characteristics towards physical science (Figure 4.8). Unlike the other PSTs, her end of semester her responses on the SDA instrument indicated more negative affect for the factors Bauer (2008) attributed to anxiety and intellectual accessibility, as well as the set of adjectives equated with emotional satisfaction. The factor attributed to interest and utility of drawing did not change during the semester, and was overall the most positive factor at 60% of the maximum scale value. Her more negative attitude towards physical science is consistent with her discussion regarding how she felt with regard to content preparation for the life and earth sciences versus physical sciences,

I think for me, physical science is a bit trickier. I think a part of it does go back when I think back to that physics class that we took spring semester sophomore year. I think when I think back to that course, the topics we learned, it wasn't something that just came naturally in a way. I guess when I think of physical science, I'm like, "This is something that's a little trickier," and I want to be able to explain it to students in a way that makes sense for them versus when I think of more life sciences; it's just a topic that, even for myself, I find a little bit more interesting. I think it's just a topic that maybe I'm a bit more excited to teach, so it's something that is a little bit less daunting when I think of it.
Figure 4.8

Avery’s Attitude Towards Physical Science Based on SDA Instrument

Note. The values for three factors and the emotional satisfaction set of bipolar adjectives from the SDA instrument (Bauer, 2008) are plotted as a percentage of the maximum scale value for the respective factor. The values for anxiety were reversed so that the percentage of maximum scale is consistent with the factors and represents a more positive attitude.
Science Teaching. Avery was unique among the four PSTs in that she did not change in her self-reported STEB during the semester (Figure 4.9). As mentioned in her overview, Avery was one of two PSTs who discussed in the reflection on her first field experience lesson that she felt confident prior to facilitating the lesson.

Figure 4.9

*Avery’s Science Teaching Efficacy Belief (STEB) Based on T-STEM Survey Instrument*

*Note.* The self-reported values for the STEB construct from the T-STEM survey instrument are reported as a percentage of the maximum scale value. The T-STEM survey was administered on two testing occasions: once at the beginning and the second at the end of the semester.
During her interview, Avery discussed her experiences planning and teaching in both her fall and spring semesters as contributing to her sense of preparation.

I think I do feel prepared. I think, for last semester and this semester, being able to see many demonstrations of how to incorporate hands-on lessons and experiments to be able to make it engaging for students, I think I do feel prepared for knowing what is the best way to have students be excited about science and ways for them to engage in the classroom. I would say maybe more on the content side, maybe a little less prepared, I think, specifically, like I said, for more older students and maybe with concepts that I still might feel a little ... that are maybe a little more complex, maybe just feeling a little bit less prepared for teaching that. But, I feel like I have all the means necessary to know how to have students be engaged in science and have them excited to learn.

While she expressed confidence in teaching based on her prior experiences, she did specifically mention drawing as supporting her STEB specifically regarding physical science. She had commented she did not feel as comfortable leading with older students, possibly due to lack of confidence in her physical science knowledge. When Avery was asked about how her ideas about teaching science had changed over the semester, she responded,

I think, with older students, it seemed a little bit daunting at first like, "Some of these scientific ideas, I don't even know if I fully understand them to be able to explain to students." But, being able to use specific strategies to help those students, I think that's something that really helped me this semester, was using **drawings**. That was a way to be able to take these ideas that seemed a little bit daunting at first like, "I don't really know if I can," for students to be able to understand this. I don't know if I can just do it by verbally saying it, but **drawing pictures** on the board for them, then having the **students**
**draw** their own pictures to be able to help explain their ideas to be able to better understand their thinking.

**Avery’s SK Learning Outcomes**

Avery’s SK learning outcomes are organized based on concepts and science drawing. The section on concepts summarizes her ideas about the water-force phenomenon during the series of lessons with explicit instruction. The findings are based on content analysis of her series of drawings, her written explanation, and her responses during the end-of-semester, semi-structured interview. The category matrix for the content analysis of concepts in drawings and written explanation was provided in Table 3.11. The category matrix for content analysis of the interview responses for new force-related conceptual knowledge was provided in Table 3.14. The section on science drawing summarizes how her drawings evolved based on deductive content analysis for aspects of model use, including model relationships, purpose and salient features, and metacognition. Schematics of each of the model aspect categories and associated measures from the drawings were depicted in Figures 3.15 – 3.17. The final category matrix used to code her drawings for aspects of model use was provided in Tables 3.13. The category matrix for content analysis of the interview responses for new science drawing knowledge was provided in Table 3.14.

**Concepts.** Avery’s progression of drawings for the water-force phenomenon (Figures 4.5 & 4.6) and her discussion during her interview indicated that she built new knowledge about intermolecular water forces during the series of lessons that included explicit instruction on drawing to reason. The results from the deductive content analysis of Avery’s first drawing, final drawing and written explanation for relevant concepts is provided in Table 4.1.
Table 4.1

*Concepts Included in Avery’s Drawings and Written Explanation for Water-Force Phenomenon*

<table>
<thead>
<tr>
<th>Big Idea</th>
<th>Concept</th>
<th>First Drawing</th>
<th>Final Drawing</th>
<th>Written Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>All matter in the Universe is made of very small particles</td>
<td>Molecular structure of water</td>
<td>○</td>
<td>●</td>
<td>○</td>
</tr>
<tr>
<td></td>
<td>Molecular charge (water polarity)</td>
<td>○</td>
<td>●</td>
<td>○</td>
</tr>
<tr>
<td></td>
<td>Particle model for matter</td>
<td>●</td>
<td>●</td>
<td>○</td>
</tr>
<tr>
<td></td>
<td>Spatial structure of liquid vs solid</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Objects can affect other objects at a distance</td>
<td>Gravity</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td></td>
<td>Magnetism analogy</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Changing the movement of an object requires a net force to be acting on it</td>
<td>Adhesion of water molecules</td>
<td>○</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td></td>
<td>Cohesion of water molecules</td>
<td>○</td>
<td>●</td>
<td>○</td>
</tr>
<tr>
<td></td>
<td>Compression force on washcloth</td>
<td>○</td>
<td>○</td>
<td>●</td>
</tr>
<tr>
<td></td>
<td>Drag force on water droplet</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td></td>
<td>Unbalanced vs balanced forces</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

*Note:* Relevant science concepts to explain the behavior of water being wrung from a washcloth in space versus on earth are based on the Big Idea Tree shown in Figure 3.2

Her reflection on a lack of change in general force and motion knowledge was consistent with the results of her ATLAST force and motion assessment results at the beginning and end of the semester, which also indicated a stable level of knowledge.
As seen in Table 4.1, Avery included more concepts related to a canonical explanation of the water-force phenomenon in her final drawing compared with her first drawing, as well as including some of the new concepts in her written explanation. She included 6 concepts in her final drawing and 3 concepts in her written explanation out of a total of 11 coded concepts (see Table 3.11). In her first drawing, she only included two of the concepts in her first drawing.

As shown in her drawings in Figures 4.5 and 4.6, Avery tended to use both visual and textual representations to express her ideas in her drawings. Even though the concepts adhesion and cohesion were not represented as visual representations in the drawings, they were included as textual representations to explain the phenomenon. Compression force was not included as a concept represented in her drawings, since it was not clear from the drawing if her reference to the wringing of the wash cloth and the curved vectors were indicating force versus the direction of the observed action.

When discussing her drawing during the semi-structured interview at the end of the semester, Avery also referred to that aspect of the drawing as indicating the observed action since she stated, “In the middle, we have the washcloth. And then, these arrows represent the direction of it being rung out.” She only discussed the force of gravity pulling the water down, but not compression force acting against the adhesion to the washcloth itself. Although Avery did include several of the forces acting on the water molecules on earth and in space, she did not draw or write about them in terms of their relative magnitude or as a system of forces acting on water.

During the interview, Avery also discussed the different forces, but not necessarily as a system of forces acting of the water molecule to result in motion. For example when discussing how her drawing supported her written explanation, she said “there's no gravity in space to be
able to pull the water droplets down, and knowing to write about the structure of the water molecules or what makes the water molecules stick together.” Therefore, the concept of unbalanced versus balanced forces was not coded in the content analysis as new conceptual knowledge in either her drawings or her written explanation.

The findings of new conceptual knowledge about intermolecular water forces based on the content analysis of Avery’s series of drawings and her written explanation were supported by her discussion of the drawings during the semi-structured interview about the changes in her series of drawings. She said, “the biggest changes was adding a bit more of those scientific terms as we learned about them like adhesion and cohesion and being able to understand how the water molecules, how they stick together.” She also discussed how the drawing helped her think through her initial ideas when she was uncertain of the explanation for the water-force phenomenon,

I do think that being able to draw it was a way to represent what we observed from first watching the video, and being able to draw it was a good way to be able to help visualize my understanding of why this occurred instead of trying to write it all down in words …

The first drawing is a bit easier to explore those ideas by drawing a picture instead of trying to write those ideas down that, at the beginning, I didn't have the clearest understanding of.

In addition, Avery discussed the role of the iterative cycle of evaluating and revising her drawings in building her knowledge. Her evaluation and revisions of her drawings were influenced by the lesson activities each week.

I think when we would receive our drawings back, knowing that, using that information that we had discussed in class and learned about and knowing, "Okay, there's got to be
some way this applies to ... There's a reason we're learning this," so it applies back to this drawing to be able to use.

However, Avery did not think her general knowledge about force and motion had changed over the course of the semester. In the interview, she attributed her understanding to the physics course that she took her sophomore year, as described below,

When I think back specifically to force and motion, a lot of it comes back to the physics class we took, ooh, spring semester sophomore year. When I think back to that class, I think of a lot of the ... That was taken online because we were not in person that semester, but thinking back to a lot of the ideas we represented through drawings, and I think specifically with forces and motions, it's much easier to be able to see a picture of maybe a car moving and being able to see that force arrow and being able to use a drawing to be able to represent that rather than reading on a page or reading an explanation that is written. It's much easier to visually be able to see that.

**Science drawing.** To explore learning outcomes related to the practice of drawing-to-reason, Avery’s series of drawings (Figures 4.4 to 4.6) were analyzed for *three aspects of model use*, including a) *model relationships*, b) *purpose and salient features*, and c) *metacognition* (see Figures 3.15 to 3.17; Table 3.14). The operationalized measures for *model relationships* were the types of translations included in the drawings (Figure 3.15). For *purpose and salient features*, the operationalized measures were inclusion of foundational images and scale tools in drawings, frequency of text for explanation versus labeling in drawings, and inclusion of non-observable structures, processes and relationships versus observable features in drawings (Figure 3.16). *Metacognition* was operationalized based on the frequency of revisions based on type in their drawings (Figure 3.17).
Quillin and Thomas (2015) contrasted a novice versus expert when comparing aspects of model use for drawing-to-reason prior to and after explicit instruction. However, in this research, the terms “more expert” versus “novice” were used to reflect that PSTs’ drawing as a way to reason was still developing from an initial starting point. The term more expert indicates an increase in the operationalized measures of the model use aspects that were coded in the PSTs’ series of drawings.

While the PSTs’ drawing-to-reason may have been novice or more expert based on the model-use aspects, they may have displayed or recognized other important uses for drawing in science during the course. As discussed in Chapter Two, there are a range of instructional purposes for drawing in science. In addition to drawing-to-reason, which was the focus of this research, Ainsworth et al. (2011) outlined other valuable purposes of drawing, including to learn, communicate, engage, and represent (Figure 4.10). These purposes range from a product-oriented focus on the final drawing to a process-oriented focus on the generation of the drawing. They are defined as distinct learning goals, but inclusion of drawing in the classroom will often target multiple purposes.
Note. Ainsworth (2011) outlined five valuable purposes to include drawings in the science classroom that range for being product-oriented to process-oriented. While outlined as distinct, inclusion of drawing in science lessons may target multiple purposes.

Based on the operationalized measure for model relationships, Avery displayed a more expert use of drawing-to-reason based since she included a greater variety of translations in her drawings as the lessons with explicit instructional interventions progressed (Table 4.2). Because this measure was not dependent on the phenomena being explained, the Cartesian diver was included as a comparison along with the drawings for the water-force phenomenon. In her Cartesian diver drawing (Figure 4.4), Avery only included a visual-text translation, for example, her representation of the increase in water pressure with vectors and with explanatory text. She included similar examples of visual-text translations in her water-force phenomenon drawings. In her interviews, Avery discussed how the visual representations in her final drawing supported writing her explanation. She shared that,
I think the drawing definitely helped to be able to have a visual to be able to translate the ideas from what the drawing was to being able to write those out. It helped as a guide for what to include in the explanation to be able to mention or to know what to mention like, "Okay, we're going to mention about how there's no gravity in space to be able to pull the water droplets down," and knowing to write about the structure of the water molecules or what makes the water molecules stick together. So, being able to have that visual, it almost acted or did act like a guide to be able to know what to include.

Table 4.2

*Types of Translations in Avery’s Drawings of Science Phenomena*

<table>
<thead>
<tr>
<th>Drawing</th>
<th>Visual-Text</th>
<th>Horizontal</th>
<th>Vertical</th>
<th>Spatial</th>
<th>Structural</th>
<th>Properties</th>
<th>Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cartesian diver</td>
<td>●</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td><em>Water-force phenomenon drawing version</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1st</td>
<td>●</td>
<td>○</td>
<td>●</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>2nd</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>3rd</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Final</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

*Note.* In the table inclusion the type of translation is indicated by ●, while no evidence of the translation type is shown by ○.

While Avery did not include vertical translations in her Cartesian diver, they were included in her water-force phenomenon drawings, and she included them for more purposes in subsequent drawing versions. In her first water-force phenomenon drawing, she included a vertical translation to show that liquid water is comprised of separate water molecules, and in her second version, she also included a vertical translation to represent the molecular structure of water compared to the observable liquid form. In addition, in her second version for the water-
force phenomenon drawings, she included a horizontal translation between water molecules
drawn as dots in her particle model for water and the stick-and-ball representation for a water
molecule.

Based on the three operationalized measures for the purpose and salient features aspect
of model use, Avery also displayed more expert use of drawing-to-reason after explicit
instruction during the series of lessons. Her use of foundational images and scale tools in both
the Cartesian diver and water-force phenomenon drawings is shown in Table 4.3. The purpose of
the inclusion of textual representations for labels versus explanations in the drawings is shown
in Figure 4.11. A graph of her inclusion of non-observable structures, processes, and
relationships versus observable features in her series of water-force phenomenon drawings is
shown in Figure 4.12. Only the versions of the water-force phenomenon are included in Figure
4.12, because the concepts for the Cartesian diver were different than for the water-force
phenomenon and are not a useful comparison.

The first operationalized measure for purpose and salient features, was the inclusion of
distinct examples of the foundational images and scale tools in drawings (Table 4.3). As
discussed previously, Avery included frames for both the Cartesian diver and the water-force
phenomenon, but the framing was used to represent a temporal sequence for the diver drawing
versus a location difference for the water-force drawings. Avery’s inclusion of framing in her
drawings for both phenomena likely reflected the instructor-modeled framing included in the
lesson as the PSTs began to generate their own drawings for the Cartesian diver. The other
foundational images and tools were projected in the classroom while the PSTs were drawing but
were not modeled to avoid influencing what observable versus non-observable features the PSTs
included in their drawings.
Table 4.3

Avery’s Use of Foundational Images and Scale Tools in Drawings

<table>
<thead>
<tr>
<th>Drawing</th>
<th>Frames</th>
<th>Magnification Tool</th>
<th>Particle Model</th>
<th>Vectors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Structure</td>
<td>Process</td>
<td>Force</td>
<td>Direction</td>
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<tr>
<td>Cartesian diver</td>
<td>●</td>
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<td>○</td>
<td>●</td>
</tr>
<tr>
<td>Water-force phenomenon drawing version</td>
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<td>1st</td>
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<td>2nd</td>
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<td>3rd</td>
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<tr>
<td>Final</td>
<td>●</td>
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<td>○</td>
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</tr>
</tbody>
</table>

Note. Within the table, inclusion the type of translation is indicated by ●, while no evidence of the translation type is shown by ○.

Avery used vectors to represent both force and direction in her Cartesian diver drawing and her drawings for the water-force phenomena. While the use of vectors for drawing-to-reason was discussed prior to the Cartesian diver and instructor-modeled prior to the water-force phenomenon, Avery’s inclusion may be more indicative of her prior knowledge for use of vectors for science drawings. In her interview, she discussed the physics class her sophomore year.

But thinking back to a lot of the ideas we represented through drawings, and I think specifically with forces and motions, it's much easier to be able to see a picture of maybe a car moving and being able to see that force arrow and being able to use a drawing to be able to represent that rather than reading on a page or reading an explanation that is written.

This experience with visual representations was common among all the PSTs in this study.

The other two foundational images and scale tools that Avery included in her water-force phenomenon drawings but not her Cartesian diver drawing were the magnification tool and
particle model. While these were discussed beforehand and projected in the classroom while the PSTs were drawing their Cartesian diver explanations, the instructor more explicitly modeled their use prior to introducing the water-force phenomenon. During the interview at the end of the semester, when asked by the researcher about where she gained visual literacy knowledge for using the foundational images and scale tools such as the magnification tool, Avery responded, “That did come from our science methods course. That was one of the strategies that we talked about, incorporating that into the drawing.”

The second operationalized measure for purpose and salient features was the purpose of textual representations included in drawings (Figure 4.11). With the exception of the Cartesian diver drawing in which most of the text was used to label, she tended to use text almost equally to label visual images in the drawing and for explanations of ideas. As discussed in the contextual overview, of the four PSTs, Avery tended to use textual representations versus visual representations to express ideas in her drawings. Where the other PSTs added on to their visual representations with a textual representation, Avery tended to express certain ideas only as text (see water-force phenomenon drawings in Figures 4.5 & 4.6).

This use of textual representation may reflect Avery’s prior experiences with drawing in science. In her fall science methods course, which focused on instruction for kindergarten to second grade, there appears to have been a focus on accurate observations, labeling, and vocabulary acquisition when using drawings. For example, during the interview at the end of the semester, Avery discussed her recall of prior experiences of drawing in science,

I would say, definitely last semester, we did in the science methods course. We did do quite a bit of, when [my instructor] would do demonstrations of experiments and things
like that, we would put ourselves in the shoes of the students to be able to draw and label pictures. But I would say, before that class, not too much.

Figure 4.11

Avery’s Inclusion of Text in Drawings to Explain Science Phenomena

Note. Text phrases were counted based on their use as a label or as an explanation in the drawings (Table 3.13). Frequency is defined as the total number of occurrences for each category of text in a drawing. The sequential drawing versions for explanation of the water-force phenomenon are referenced as 1st, 2nd, 3rd, and final water-force phenomenon.

In addition, her use of textual representation appeared to reflect a focus on having accurate definitions and concern about ability to accurately draw a concept due to a limited understanding, which are more product-oriented concerns for drawing. When asked about her perceived challenges of drawing versus writing, Avery said that “… specifically the more
scientific vocabulary terms, it would be a bit easier to write out those definitions and verbally explain it or in writing rather than trying to draw it out.” The challenges of accurately drawing a concept seemed to be her biggest concern.

I would say that was the biggest challenge of maybe not ... There were times of not fully understanding a concept and then trying to add that to the drawing but not fully understanding of how to apply it to adding onto the drawing.

Her comments reflect a more product-oriented use of drawing, such as of drawing-to-learn, since she appeared to be drawing some concepts to remember them, but not necessarily because they helped explain her own reasoning about the phenomenon.

The third operationalized measure for the purpose and salient features aspect of model use was the inclusion of non-observable structures, processes, and relationships versus observable features (Figure 4.12). Of the six distinct non-observable examples in her final version of the water-force phenomenon (Figure 4.6), two of the concepts, adhesion and cohesion, were included only as textual representations. This may reflect Avery’s concern about how to visually represent ideas accurately. However, based on both textual and visual representations, Avery did include more salient features in her drawing after explicit instruction, since later drawing versions included more non-observables as part of her explanation for the water-force phenomenon compared to her first drawing. Therefore, while Avery did display more expert use of drawing-to-reason based on inclusion of salient features, her focus on accuracy of science concepts and their definitions may have limited her use of drawing for more product-oriented purposes such as to drawing-to-communicate or drawing-to-learn, versus the more process oriented purpose of drawing-to-reason. This more product-oriented use of drawing was also evident in the operationalized measure for the model use aspect metacognition.
Note. The drawing version on the x-axis refers to the phenomenon of wringing water from a washcloth in space versus on earth. The frequency on the y-axis refers to the total number of different observable features (Table 3.12) or non-observable structures, processes, and relationships (Table 3.11) coded in each drawing. There was a maximum of 8 distinct observable features and 11 distinct non-observable structures, processes and relationships used. The included representation of the observable features and non-observable structures, processes, and relationships could be either textual or visual in the drawing.

Metacognition was the last aspect of model use that was evaluated by deductively coding for types of revisions or questions (Figure 3.17) in the PSTs’ series of water-force phenomenon drawings. The revisions to drawings were categorized as being based on content from the lesson activities (content revisions) or prompted by instructor feedback on the drawings (prompted
revisions). The questions were ideas or information about which PSTs indicated they still wondered in their drawings. The frequency of revisions and questions included in Avery’s series of water-force phenomenon drawings are shown in Figure 4.13.

Of the four PSTs, Avery had the fewest revisions and questions in her series of drawings. Most of her changes reflected incorporation of the content from the weekly lessons’ activities. Her one prompted revision regarded whether there was a liquid film on the washcloth on earth, which was not included in her first drawing for the water-force phenomenon. In her second drawing she included text to explain there was a thin layer of water on the washcloth that she speculated as to whether it could be felt but not seen, and she drew small dashes around the perimeter of the represented washcloth to represent the layer of water.

In her first drawing, she had included two questions, “Why does water still form a layer around the washcloth [in space]?” and “Where does the water go once the wash cloth is not being [w]rung out?”, and they appeared to still be unanswered in her final drawing. Although she had written about cohesion causing water molecules to stick together and adhesion causing water molecules to stick to the washcloth, her two questions suggest that she did not fully understand the balance of forces resulting in the observed phenomenon or how to connect the concepts of cohesion and adhesion that had been explored during the lesson to the behavior of the water in space.
Figure 4.13

Avery’s Operationalized Measures for Model Use Based on Metacognition

Note. Prompted revisions are changes in PSTs’ drawings due to an instructor prompt. Content revisions are changes based on lesson content. Questions are things that PSTs indicated they still wondered about in their drawings. Frequency on the x-axis is the total number revisions or questions in a drawing. The sequential drawing versions for explanation of the water-force phenomenon are referenced as 1st, 2nd, 3rd, and final on the y-axis.

Avery’s drawing revisions were more consistent with a product-oriented purpose for drawings, such as drawing-to-communicate with a focus on recording what content was covered
during lesson activities. The organized and detailed labeling of her drawings conveyed this product-oriented use as well. During her interview, Avery discussed her revisions,

I think a difference too is then adding a bit more scientific terms. You can see here cohesion and adhesion, including those terms, but also still asking a bit of questions for, I think just here on the washcloth in space. That's maybe something, when we're doing drawings, you think of labeling them and writing ideas out. That was something I didn't originally think to add, but, in a drawing, we could add questions.

While drawing-to-communicate and other more product-oriented purposes are valuable uses of drawing in the classroom, based on the measures for metacognition, Avery displayed more novice use of drawing-to-reason.

In summary for the science drawing, Avery displayed a mixture of novice and more expert use of drawing-to-reason depending on the model use aspect. For model relationships, she demonstrated more expert use that was evidenced by the increased types of translations she included in her drawings as the lessons progressed. For purpose and salient features, she demonstrated more expert use by including more non-observable structures, processes, and relationships to explain the water-force phenomenon as she revised her drawings. However, her focus on labeling and science vocabulary usage as a goal for her drawings suggested a more product-oriented use of drawing, which for the purpose of drawing-to-reason, would be more novice use. The measures for metacognition also suggested a more product-oriented use of drawings.

Avery’s PCK Learning Outcomes

PCK was the final learning outcome of interest for the science methods course with explicit instruction on drawing-to-reason. The PSTs’ lesson plans and their interview discussions
of facilitating their lessons were the primary data used to explore how their incorporation of
drawing as an instructional strategy would support their students’ use of drawing. As mentioned
in Chapter Three for the methodology, the data to explore this learning outcome was more
limited due to constraints in the field experiences such as time in a single semester for planning
and facilitating their own science lessons and the limited availability of the field mentor teachers
for coordination of the science methods course activities due to their classroom responsibilities
and schedule. The incorporation of drawing in the lesson plans and interview responses was
deductively coded (Table 3.15) based on whether it would support elementary students’ novice
versus more expert model use of drawing-to-reason. The coding was based on the three model
aspects, including model relationships, purpose and salient features, and metacognition, which
were used to explore how the PSTs used drawing for their own SK learning.

The results from coding Avery’s lesson plans for the first and second field experience
weeks are shown in Table 4.4. As discussed in the subsection about her field experience, Avery
used the probe “Darkness at Night” (Keeley et al., 2007) in her first week’s lesson. She did
include drawing as a communication mode for students to express their ideas during the lesson.
Because she was intentional about providing students multimodal ways to communicate during
group discussions, her lessons would support her students recognizing multiple ways to represent
science ideas. As seen in Figure 3.6, the first field experience lesson was facilitated after the first
week of the lessons with explicit instruction on drawing to reason. However, Avery’s inclusion of
drawing at this point in the semester may reflect her prior experience with drawing for her
physics class and her prior science methods course in the fall, since her students were
representing as a way to communicate their answers, not necessarily to reason about an
explanation for the pattern of day and night. Because the purpose of the drawings in Avery’s first
lesson were used primarily for communication, the model aspects of purpose and salient features and metacognition were coded as novice use for drawing-to-reason.

**Table 4.4**

*Avery’s Incorporation of Drawing in Her Field Experience Lesson Plans*

<table>
<thead>
<tr>
<th>Field Experience Lesson Plan</th>
<th>Model Use Aspects</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Model Relationships</td>
</tr>
<tr>
<td>Week One: Page Keeley Probe</td>
<td>●</td>
</tr>
<tr>
<td>Week Two: Discrepant Event</td>
<td>●</td>
</tr>
</tbody>
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ø = No drawing; ○ = Novice; ● = More Expert

*Note.* Symbols in tables indicate results from coding for how PSTs’ planned instruction would be anticipated to support elementary students’ use of drawing as the science practice of modeling based on the aspects of model relationships, purpose and salient features, and metacognition (Table 3.15).

In her second field week lesson with the bottle rockets, Avery also included drawing to record observations of the canned rocket launching and as a mode for students to share their ideas during discussion, which would support students recognizing multiple models for similar ideas. For example, when asked if students referred to their drawings as they shared their ideas during the group discussion, Avery responded,

I would say that was something that we encouraged as they were explaining their thinking of why they thought that the rockets were able to launch. We encouraged them to refer back and be like, "Okay, what did you draw in your picture? How does that help
explain what you're "trying to verbally explain, going back to that drawing.

In addition, she encouraged the students to use their drawings to explain what was happening to cause the canister to launch, which would support the students use of drawing as a tool for thinking and to record more salient, non-observable features to explain the phenomenon. She was also intentional about supporting the students’ views of drawing as valuable and purposeful for learning science, stating in her interview that,

Part of it, too, is we didn't want the students to feel like they drew their observations just for drawing them, but to be able to show them that there was a reason that we wanted them to be able to refer back, or there was a reason we wanted them to draw their pictures or draw their understanding to be able to refer back to it and not just have it as a time for students to be like, "Okay, we're just going to draw for fun." It is fun and the students do enjoy that, but being able to help show them that there's a reason for doing it, to be able to help them verbalize their understanding.

Overall, Avery’s discussion of her views on drawing in science, she tended to focus more on purposes such as drawing-to-communicate and drawing-to-learn, versus drawing-to-reason. For example when asked how she envisioned incorporating drawing in her future instruction, she responded,

I think that drawings, it's something that can be used as a formative assessment to be able to collect those and be able to see a student's thinking or see their understanding. If they have a drawing that is very detailed and labeled, you're able to see their understanding of that topic versus maybe if it's a drawing that... collect observation sheets from students and it's a drawing that maybe isn't quite correct, you'd be able to know that that student needs a bit of extra support to be able to understand that topic.
For the metacognitive aspect of model use, Avery’s lesson plan did not indicate explicit instruction to support drawing-to-reason, such as visual literacy or modeling interventions. Therefore, the students’ metacognitive use of their drawings to evaluate their thinking would be limited. However, the use of drawings for modeling was something that Avery seemed to consider to build on the activity and get the students to “think a little bit deeper,” but was constrained by time to be able to implement the create, evaluate and revise process of modeling. In her interview when discussing the lesson she shared,

This was an experiment that we could build upon. If they ran multiple days, these are some other things we could have done, but then having students be able to think a little bit deeper, at the end, we asked them questions like, "How do you think water temperature would affect the rocket launches?" We did answer this one a bit, the size of the tablets, but how much difference in water? Because, we added the same amount of water to each one. The canisters were pretty small, but even if we could affect maybe the height of how high the rockets go by adding parts to make it more of a rocket.

In discussing what she had learned about science instruction by focusing on drawing during the semester, Avery shared about the value of specific visual literacy interventions, such as the foundational images and scale tools. As discussed for her own learning about force and motion, as well as how she implemented drawing for her own teaching, Avery focused on accuracy of observation and labeling as goals for drawing,

…Specifically, I think of the one where it showed a magnifying glass zooming in and specifically labeling pictures and things like that to be able to help students feel like it's important to understand that there's a purpose for their drawing and that there's different
ways to use drawings in the classroom to be able to help them understand that there's a purpose why they're doing those drawings. It can help. I think those specific strategies for the students can help them better understand, even going back to what I was saying earlier about students maybe not understanding quite the [specifics] of drawing, using the plants. You could use that magnifying to be able to help students understand, "Okay, this is what's happening inside a plant." Even if we're not able to see that, you could use a drawing like that to be [understand what is happening inside].

Summary of Avery’s Learning Outcomes

This section of Chapter 4 described Avery’s learning outcomes based on affective characteristics, SK, and PCK, which all appeared to have changed during the science methods course that incorporated explicit instruction on drawing-to-reason.

Both the quantitative and qualitative data strands indicated changes in Avery’s affective characteristics towards drawing during the semester. Avery expressed an overall positive attitude towards drawing at the beginning of the semester, which became more positive by the end of the semester, based on the SDA instrument and her interview responses. Avery was a detail-oriented and very organized PST, and the instructional interventions appeared to help her begin to recognize that the purpose of drawings was to express emerging ideas, not perfect, final representations, which supported her more positive self-efficacy towards drawing. In interviews she frequently discussed the value of drawing and related it to supporting students’ communication and teachers’ assessment of their understanding. She also expressed interest in incorporating drawing as an instructional strategy in the future. Avery’s STEB based on the T-STEM instrument also was positive at the beginning of the semester, and it remained unchanged at the end of the semester. This was consistent with her expressed level of confidence for
facilitating her lesson for the first field experience week. Unlike the other three PSTs’ in this study, Avery’s attitude towards physical science became more negative during the semester based on her responses in the SDA instrument, which may be related to her expressed concern about physical science SK, particularly for the upper elementary grades.

Avery acquired SK about intermolecular water forces during the semester based on the analysis of her drawings and written explanation, and she developed more expert use of drawing-to-reason based on some of the analyzed model aspects, such as model relationships and salient features. However, Avery tended to focus on accuracy of labeling and science vocabulary use in her drawings, which may have reflected her prior experiences with drawing for other courses. While drawing-to-learn and drawing-to-communicate (Figure 4.10) are valuable purposes for science drawing (Ainsworth et al., 2011), they are more product-oriented uses compared to drawing-to-reason, which is process-oriented and the focus on this research.

Avery also developed PCK regarding drawing as an instructional strategy in science. In her own teaching, she incorporated drawing in her science lessons during both field experience lessons, but her inclusion of drawing during the second field experience would better support her elementary students developing more expert model use of drawing-to-reason. In the lesson during the second field week, she was more intentional about having her students include non-observable, salient features in their drawings to explain their ideas about the phenomenon with the canister rocket. Allotted science instructional time during her field experience weeks may have limited the instructional interventions from the science methods course that Avery included in her own instruction. During her interview, she reflected on the usefulness of the foundational images and scale tools from the science methods course and the re-iterative drawing cycle of create, evaluate, and revise, but did not include those in her own instruction. When reflecting on
drawing during the second lesson and for her future instruction as a teacher, Avery tended to focus on its value for more product-oriented purposes such as communication (Figure 4.10) to assess student learning.

**Eileen**

Two attributes that stood for Eileen for the semester were her self-awareness and carefulness both regarding herself as a learner and as a future teacher. While she was not necessarily the first to contribute to class discussions, she always added valuable questions and input. One thing she frequently could be counted on was openly expressing her thoughts without worrying about the perception or judgement of others. One example that stood out from the semester was her comment about not really knowing what to draw for an explanation of the Cartesian diver phenomenon, as she worked to create her sketch. As with Avery, she put her best effort into work both for in class assignments, as well as in the field, and was consistently in the top 95th percentile of grades awarded on assessed assignments. Her field teacher commented in an email about loving her energy in the classroom with students. Eileen expressed a constructivist, student-centered teaching orientation in her interview at the end of the semester, stating “I'd say they best learn about science through getting a chance to do science, and then through questioning the students to see what they know, and try to get them to reach those conclusions.” This orientation was reflected in her lesson facilitation when she shared questions she had used during the group discussions,

Then some of the questions that we asked also related to what we asked in class. Phrasing some of them as, "Why do you think that?", or, "What do you think is happening?" Then asking them, "What is happening?" That was I think the two biggest things from this lesson. At the end of our lesson, we also gave the students a chance to discuss why they
thought, on whether the cookie crumbles weighed more or the whole cookie weighed more, with their partners. We had a few share out to the class. So that discussion piece.

Initial Science Epistemological Beliefs

In the Keeley’s (2010) probe “Doing Science” (Figure 4.2) Eileen indicated that she most agreed with Tamara’s statement that “I think there is a definite set of steps all scientists follow called the scientific method.” She stated that she agreed with Tamara because “we have been taught that science is methodical and that scientists always follow the steps in the scientific method, even if those steps look different depending on the question” (Eileen, Probe Response, Jan. 24, 2022). She disagreed with the other statements because she reasoned that scientists are prescriptive in using the science method for all investigations and that they use investigations other than experiments to build knowledge, noting in her explanation that,

I disagree with Erin that all scientists do experiments because my psychology research class told us that sometimes psychologists reuse already published data to answer a new question. I partially disagree with Marcus. While sometimes scientists use different methods to test their questions, they still use the same method of the scientific method. I partially disagree with Antoine. While doing science can involve trial and error, it is still methodical and organized in what they try. They have to have a reason to try one method (Eileen, Probe Response, Jan. 24, 2022).

Therefore, Eileen’s prior course experiences appeared to have strongly influenced her mixed epistemological view of the nature of knowing in science, including the source of knowledge and the ways that knowledge is accumulated. On one hand she expressed a more positivist view, since she referenced that she had been taught scientists always follow the scientific method. However, her prior coursework also informed a more interpretivist view for the source of
knowledge, since she mentioned her experiences with secondary data from her psychological research course.

**Field Experience Lessons**

For her field experience during the semester, Eileen was assigned to a third grade elementary classroom. Her mentor teacher in the field gave her broad leeway for the content focus, because during the spring field assignment, her assigned classroom would not be covering any science content, just ELA, mathematics and social studies. Eileen’s mentor teacher had covered all the science content she planned to include during the 2021 fall semester. Eileen and her partner selected the probe “Cookie Crumbles” (Keeley et al., 2005) after using it for some of the in-person class activities and discussions, because they thought their students would enjoy the probe and it was consistent with content their mentor teacher covered in the fall related to third grade physical science standards in North Carolina’s course of study (NCDPI, 2021a). The “Cookie Crumbles” probe elicited students’ ideas about conservation of matter based on everyday items. In the probe the students had to decide if they thought a whole cookie had the same mass after it was broken into a pile of pieces and crumbs, so it explored their ideas about the whole as a sum of its parts. Note that for elementary students, the probe used the concept of weight for comparing the whole cookie versus the pieces and crumbs, because students below fifth grade might not be familiar with the term or concept of mass.

As Eileen noted in her reflection, while she had planned to lead the lesson independently with a small group of students, on the day they had planned to facilitate the lesson, her mentor teacher asked her and her partner to co-teach the whole class during the students’ lunch period. The majority of the lesson was facilitated by Eileen, because it was difficult without prior preparation to evenly divide up the responsibilities. Her reflection also illustrated her self
awareness regarding teaching because she reflected on feeling overwhelmed when managing the whole-group discourse and identified ideas to try in future lesson facilitation. In addition, she was cognizant that she had not been able to balance the co-teaching with her partner. She also recognized how the experience had helped her develop flexibility as a teacher to adapt her plans to an unexpected teaching context.

For her second week of teaching in the field, she chose the phenomenon “Cloud in a Bottle” (Science World, n.d.). The phenomenon involved adding a small volume (~50 mL) of isopropyl alcohol to a clear two liter bottle, which was sealed with a cork containing an inflating needle to attach to a bicycle pump. After sealing the bottle with the cork, the bottle was swirled to distribute the isopropyl alcohol on the sides of the bottle, and then, the bicycle pump was used to pressurize the bottle. The increased pressure caused the liquid alcohol to evaporate due to the increased energy in the closed system. The bottle was warmer to the touch when pressurized because of the compression of the gas molecules. When the seal was then quickly removed, a cloud formed inside the bottle as the alcohol condensed into suspended droplets as the gas in the bottle was able to rapidly expand into the air outside the bottle. Eileen structured her lesson to have her students focus on the different states of matter they observed and the change of thermal energy in the system, as well as make connections to the water cycle.

**Force and Motion Knowledge**

As discussed for Avery, the ATLAST Force and Motion assessment (Horizons Research Inc., 2011) was used to characterize the PSTs’ general background knowledge about force and motion. The PSTs’ median score on the ATLAST assessment in this study was similar to the reported mean of middle school physical science teachers who were used to develop the instrument. As shown in Figure 4.14, Eileen’s correct responses were slightly lower than the
group median at the beginning of the semester but were consistent with the group median at the end of the semester.

**Figure 4.14**

*Eileen’s ATLAST Force and Motion Responses Compared to the PSTs’ Group Median*

Note. Eileen’s correct responses at the beginning (blue bar) and end of the semester (orange bar) compared with the median for all four PSTs (gray line). Based on the guidelines for use of the ATLAST Force & Motion Teacher Assessment (Horizon Research, Inc, 2011) the specific values are not listed. The bars are plotted with the median line to provide qualitative information for Eileen’s general knowledge about force and motion relative to the other PSTs.

The change in correct responses from the beginning to the end of the semester likely may represent variability between testing occasions since Horizons Research Inc. (2011) reported a retest reliability of 0.88. Eileen selected at least one correct response on all force and motion sub-ideas included in the assessment (see Appendix A) with the exception of sub-idea E that if an
object is moving faster and faster, then there is a net force acting on the object in the same
direction as the motion. In addition, she selected correct responses for questions assessing all
three types of knowledge (see Appendix A), which Horizons Research Inc. (2011) categorized as
content knowledge, knowledge use to analyze/diagnose student thinking, and knowledge use for
instructional decisions. While Eileen still has room for growth, her force and motion knowledge
is consistent with literature on physical science content knowledge of preservice teachers Everett
et al., 2009), as well as undergraduate students in general (Bahtaji, 2023).

**Science Drawings of Force-related Phenomena**

Eileen’s drawings from the semester are shown in Figures 4.15 to 4.17, including her
drawing to explain the Cartesian diver phenomenon (Figure 4.15), her first drawing for her
water-force phenomenon on the second week of the series of lessons with explicit instruction on
drawing-to-reason (Figure 4.16), and her final drawing for the water-force phenomenon (Figure
4.17). The description of the drawings here will mainly focus on qualitative description, and a
more detailed analysis based on the coding scheme outlined in the methodology will be
presented below for the SK learning outcomes.

As seen in Figure 4.15, Eileen separated her Cartesian diver drawing into frames based
on a temporal pattern of before, during, and after by dividing the horizontal space into thirds with
vertical lines. This reflected the visual literacy instruction in the class lesson prior to the
Cartesian diver demonstration, as well as emphasis on how to create temporal frames that were
instructor-modeled for the PSTs immediately prior to generating their drawings. While the drawn
images were placed in the center of each of three frames, most of Eileen’s drawings were white
space. The images occupied less than half of the vertical space and approximately two-thirds of
the horizontal space. Like the other PSTs, her Cartesian diver drawing focused predominantly on
the observable features; however, she did appear to include limited non-observable processes to express her initial ideas about the why the diver sank to the bottom of the bottle when squeezed.

In contrast to the other PSTs, Eileen did not note the air space at the top of the bottle, although she did include a space between the water and the top of the bottle. The liquid water was represented as a wavy line, which appeared to be represented at a similar level in the bottle in all three frames. The image for the diver is also less detailed than in the drawings for the other PSTs. The only other foundational image or scale tool that she used in her Cartesian diver drawing was the vector. In the middle and last frames, Eileen included curved, upward-directed, and downward-directed vectors to represent her idea of some property of the water increasing or decreasing. She also used straight, downward-directed and upward-directed vectors to represent the sinking and rising of the diver. Inward-directed straight arrows in proximity to the hand images were used to represent squeezing and releasing the bottle as the diver sank to the bottom or floated to the top of the water.

In her first drawing of the water-force phenomenon (Figure 4.16), Eileen included more non-observable structures, processes, and relationships along with observable features. Consistent with her Cartesian diver drawing (Figure 4.15), she included framing, but used a spatial comparison of earth versus outer space instead of the temporal framing. Unlike the framing for the Cartesian diver, Eileen did not draw a vertical line to divide the horizontal space, but instead folded the paper to create a crease. The orientation of images in her drawing was horizontal, but her images and text in each frame were aligned to the left of the frame and did not take up the full width of space. Vertically the images were aligned towards the top of the page and only filled approximately one third of the available space. In her drawings, the labels, lines, and shapes were drawn with light, thin lines.
Figure 4.15

Eileen’s Cartesian diver Drawing
Figure 4.16

Eileen’s First Drawing of Water-Force Phenomenon
Figure 4.17

Eileen’s Final Drawing of Water-Force Phenomenon
The washcloths on both earth and in space were drawn as an oval shape outlined by straight line with diagonal lines filling the inner space to represent the twisting of the material. For earth, Eileen also included the water bin that was below the washcloth to catch the falling water, which was not included in the other PSTs’ drawings. Eileen included text in the drawings to label drawn elements and to provide explanation about the phenomena, but her visual representations appeared to be a more prominent focus in her drawings.

There were a couple of noteworthy attributes of Eileen’s drawings of the water-force phenomenon (Figures 4.16 & 4.17) compared with the other PSTs. One was the smaller scale of Eileen’s images and texts. As noted above, her drawings had the largest amount of white space of the four PSTs. Another important attribute of her drawings compared with the other PSTs was the lighter and thinner pencil markings used for the drawn images. The textual representations were also small but were proportional to the magnitude of the images.

Her representations of visible water in her drawings varied and included textual representation and visual representations of a liquid film, which differed on earth versus in space, and tear-shaped droplets. Like Avery, Eileen visually represented the water film differently on earth than in outer space. On earth, she represented the water film on the washcloth by shading space inside the elongated oval representing the washcloth but did not draw any feature outside the oval. In her first drawing of the water-force phenomenon (Figure 4.16), Eileen did not include an indication of a water film on the washcloth on earth, but revised the drawing based on instructor prompts. In space, Eileen represented the water film on the washcloth as a layer of spherical drops around the outside of the elongated oval representing the washcloth but did not shade the inside. In response to a prompt from the instructor, she revised her first drawing (Figure 4.16) to have the spherical drops touching and completely surround the washcloth in her
subsequent drawing versions, including the final version (Figure 4.17). She included water as tear-shaped droplets falling from the washcloth on earth, and as mentioned previously, included the water bin that had been part of the hands-on activity with wringing out the washcloth during class.

Eileen also incorporated more of the foundational images and scale tools (Figure 3.4) in her drawings of the water-force phenomenon (Figures 4.16 & 4.17) compared to her Cartesian diver drawing (Figure 4.15). In the drawings for the water-force phenomenon, vectors were used to represent direction and force. Vector shape and direction represented distinct types and direction of force, including a curved arrow for compression force from hands and a downward, straight arrow for gravity. She also included small arrows directed inward towards the washcloth to represent adhesion in space. On earth, she used the magnification tool to visually draw a water molecule on the surface of the washcloth and included a small vector labeled to represent adhesion. Like Avery, Eileen placed textual representations for labels and explanations near the visual representations of her ideas, but she did not use a straight line or arrow to tag the image with the text.

She used the magnifier scale tool (Figure 3.6) in her water-force phenomenon drawings, to vertically translate between visible water and its particle composition, between visible water and its molecular structure, and to show potential charge on the washcloth. A distinct idea that Eileen included in her particle model, was a spatial difference between water molecules in liquid water on earth versus space. In the space frame of her first and final water-force drawing versions (Figures 4.16 & 4.17) the dots in the magnification tool representing the non-observable particle structure of water are closer together than the dots in the magnification tool for earth.
She includes text beside the magnification tool in space to explain her thinking. Her representations for water included the textual representation, a particle model based on the foundational images (Figure 3.6), and a two-dimensional, stick-and-ball model with the hydrogen and oxygen atoms labeled with both the element symbol and charge.

**Eileen’s Learning Outcomes Based on Affective Characteristics**

This section synthesizes the quantitative and qualitative data strands exploring Eileen’s affective characteristics during the science methods course with explicit instruction on drawing-to-reason. Note that all quotes in the following sections are from Eileen’s semi-structured at the end of the semester (Eileen, Interview, May 24, 2022). Because affective characteristics are targeted towards something (Anderson and Bourke, 2000), this section is organized by affective characteristics towards drawing, physical science, and science teaching.

**Drawing.** With the exception of the emotional satisfaction set of adjectives, Eileen’s attitude towards drawing was similar at the end compared to the beginning of the semester based on the SDA instrument’s factors of anxiety, intellectual accessibility, and interest & utility (Figure 4.18). In addition, compared with the other three PSTs, she tended to express a more negative attitude towards drawing in general. Eileen also discussed her more negative attitude towards drawing at the beginning of the semester during her semi-structured interview. However, she did express a positive change in attitude over the semester, as well as a change in perceived value. In response to the question of reflecting on how she felt about drawing this semester, she responded that,

I feel better about it. I feel like now, drawing can be more helpful for my learning. I still don't love drawing, myself. It still makes me a little self conscious…. But I think now, I can see that there's a benefit to helping me learn when I draw. Whereas before, not only
did I not really like drawing, but I didn't really see the point in why we were drawing for school. So now I feel like it does help me learn, and also see what I understand or don't understand a little more.

**Figure 4.18**

_Eileen’s Attitude Towards Drawing Based on SDA Instrument_

![Graph showing Eileen's attitude towards drawing based on SDA Instrument](chart)

*Note.* The values for three factors and the emotional satisfaction set of bipolar adjectives from the SDA instrument (Bauer, 2008) are plotted as a percentage of the maximum scale value for the respective factor. The values for anxiety were reversed so that the percentage of maximum scale is consistent with the factors and represents a more positive attitude.
Similar to the other PSTs, value was the affective characteristic most frequently noted in Eileen’s interviews. Based on her responses, Eileen associated the value of drawing with how it supported her metacognitive awareness of both her own knowledge and her students’ knowledge. In her comment above, she addressed how it supported her own thinking. In her discussion of how drawing might be useful as a science teaching strategy, she stated, “I have realized how much it can help you with understanding student thinking. Seeing on that level, like I said earlier, about how deep they understand a topic.”

She also reflected on the potential value for students of the visual literacy interventions with the foundational images and scale tools and the modeling interventions, commenting “the different instructions…is something that I do wish that we included with our cloud in the bottle experiment,” and that “if they had given them more time to revise their drawings…their drawings could have been even better too.” Her lesson for the “Cloud in the Bottle” (Science World, n.d.) originally was planned for 30 minutes, but ended up only having approximately 15 minutes with the students the day of the lesson, which limited what she implemented in her field experience. Eileen also recognized that the modeling process of creating, evaluating and revising would need multiple days to implement, commenting “granted, it isn’t our class, so we couldn’t really take that time to have a multiple day lesson.”

While Eileen did not mention her self-efficacy towards drawing as often in the interview as Avery did, she did discuss some specific ways that she felt more confident. Her responses reflected the focus of affective interventions during explicit instruction on drawing, for example, in response to the question of what she learned about drawing during the semester, she said, “Something that I learned personally is not to stress about making the drawings perfect, or look nice. Because I learned that the point of the science drawings isn't necessarily to
look nice, but to show what you're seeing. So that's something that I'll take to my students.

In addition, the visual literacy interventions seemed to have influenced her perception of drawing, because she commented on the foundational images and scale tools when contrasting how she formerly perceived drawing versus what she learned about drawing.

I know when I was a student, it would frustrate me that I couldn't get mine to look nice. It made me not want to do it. But then I think I've also learned how important the labeling of your drawings is, and the different drawing instructions that we could give kids.

However, the reference to labeling was likely from experiences with drawing from either her prior science methods course for the early grades or in her physics course, since labeling was not an instructional intervention emphasized during the semester.

Throughout the semester, Eileen seemed self-aware of her level of SK and careful in her approach to learning. Her drawings for both the Cartesian diver (Figure 4.15) and the water-force phenomenon (Figures 4.16 & 4.17), seemed to reflect Eileen’s uncertainty about drawing her ideas. Her drawings were more sparse compared to the other PSTs and she tended to draw with lighter, thinner pencil markings. Kress and VanLeeuwen in “Reading Images: The Grammar of Visual Designs” (2006) discussed how visual elements attract attention due to the contrast with the background, their size, sharpness, and tonal value (ie darkness or lightness) and can convey a message of value or importance, and in Eileen’s drawings, possibly a lack of value or uncertainty about their importance for her explanation.

As noted in her context, Eileen had commented about not knowing what to draw when first starting the Cartesian diver sketch. She commented in the semi-structured interview that
drawing can be more challenging than writing and noted how it forced her to really think about what she knew.

For me, I think it was also a lot easier to write out an explanation in my notebook, versus draw the explanation. So I think drawing pushed my thinking deeper. Because I do think with writing, that sometimes you're able to ... I think it's easier for me to put my thinking in words. But also, sometimes you're able to write around the question a little bit. You can't really do that when you're drawing.

**Physical science.** With the exception of the factor associated with intellectual accessibility from the SDA instrument, Eileen’s attitude towards physical science at the end of the semester was similar to the beginning of the semester (Figure 4.19). The factors that Bauer (2008) attributed to interest and utility and the adjective set attributed to emotional satisfication overall indicated a positive attitude towards physical science, while the factor attributed to anxiety was neutral since her response ranged from 49% to 54% of the maximum scale value at the beginning and end of the semester, respectively.

The decrease in the factor from the SDA attributed by Bauer (2008) to intellectual accessibility was consistent with Eileen’s reflection on her perceived SK during her interview.

I know that our program also does give us a lot more content knowledge, being a STEM program. From what I've heard about my friends in other elementary ed programs, we take way more sciences classes than they have. Especially with the physics class. But I still feel it would be good to have more content knowledge for science.

In addition, when asked about her perceived preparation for teaching science, Eileen touched on her SK in physical science in her answer.

I still think there is some science content knowledge that I don't necessarily have. But I
think I know more places to get that knowledge now. I think that even if I had, I don't think you could ever know all the science content knowledge.

**Figure 4.19**

*Eileen’s Attitude Towards Physical Science Based on SDA Instrument*

![Graph showing Eileen's attitude](image)

*Note.* The values for three factors and the emotional satisfaction set of bipolar adjectives from the SDA instrument (Bauer, 2008) are plotted as a percentage of the maximum scale value for the respective factor. The values for anxiety were reversed so that the percentage of maximum scale is consistent with the factors and represents a more positive attitude.
Similar to Avery, she shared that she was “a little more confident in life or earth science, over physical science,” because she “definitely remember[ed] spending more time on those strands of science when [she] was growing up.” Consistent with her reflective nature mentioned in the context section, Eileen elaborated on feeling different levels of confidence within the physical science strand, adding “… mass and volume … would be a physical science thing that I feel more confident with. But some other parts of physics, I can memorize what the textbook says is why it's happening, but I still don't really understand why that's the case.” Her choice of the probe “Cookie Crumbles” (Keeley, 2010) for her first field experience was consistent with her stated confidence level with certain content areas in physical science.

**Science Teaching.** In contrast to Avery, Eileen’s STEB did increase over the course of the semester, based on the results from the T-STEM instrument (Figure 4.20). In her reflection for her first field experience lesson on the Paige Keeley probe (2010), Eileen shared that she felt nervous prior to the lesson because it was her first time teaching during the spring semester (Eileen, First Field Experience Reflection, Jan. 24, 2022). She also provided a specific example in her reflection of what she had learned as a teacher from facilitating the lesson with the “Cookie Crumbles” (Keeley, 2010) probe since she had to adapt the implementation of the lesson at the last minute. In her reflection, she noted she did not consider flexibility while teaching to be one of her strong skills, but realized that she had adapted to changing circumstances successfully. So this could be considered a mastery experience that contributed to her STEB, based on Bandura’s theory of self-efficacy (Bandura, 1997).
Eileen’s Science Teaching Efficacy Belief (STEB) Based on T-STEM Survey Instrument

Note. The self-reported values for the STEB construct from the T-STEM survey instrument are reported as a percentage of the maximum scale value. The T-STEM survey was administered on two testing occasions: once at the beginning and the second at the end of the semester.

Eileen also discussed more positive STEB during her interview, which she connected to both acquiring more SK but also specifically to drawing.

I feel pretty prepared. I think I have more strategies to teach with, and I know more things about the pedagogy side of things. The different types of questioning, and drawing, and having them do science. I still think there is some science content knowledge that I don't necessarily have. But I think I know more places to get that knowledge now. I think that even if I had, I don't think you could ever know all the science content knowledge.
As illustrated by the quote, one noteworthy aspect of Eileen’s discussion during her interview was her reflection on her recognition for the need for continued learning as a teacher. She had also discussed this continual learning in her affective characteristics towards physical science, for example, she followed the quote above with that statement that “… even if I had learned all the science content knowledge, I would probably have to get a refresher anyway when I was teaching it. Because I definitely would forget something.”

**Eileen’s SK Learning Outcomes**

Eileen’s SK learning outcomes are organized based on concepts and science drawing. The section on concepts summarizes her ideas about the water-force phenomenon during the series of lessons with explicit instruction. The findings are based on content analysis of her series of drawings, her written explanation, and her responses during the end-of-semester, semi-structured interview. The category matrix for the content analysis of concepts in drawings and written explanation was provided in Table 3.11. The category matrix for content analysis of the interview responses for new force-related conceptual knowledge was provided in Table 3.14. The section on science drawing summarizes how her drawings evolved based on deductive content analysis for aspects of model use, including model relationships, purpose and salient features, and metacognition. Schematics of each of the model aspect categories and associated measures from the drawings were depicted in Figures 3.15 – 3.17. The final category matrix used to code her drawings for aspects of model use was provided in Tables 3.13. The category matrix for content analysis of the interview responses for new science drawing knowledge was provided in Table 3.14.

**Concepts.** Similar to Avery, Eileen’s progression of drawings for the water-force phenomenon (Figures 4.16 & 4.17) and her discussion during her interview indicated that she
acquired new knowledge about intermolecular water forces during the series of lessons that included explicit instruction on drawing to reason. The results from the deductive content analysis of Eileen’s first drawing, final drawing and written explanation for relevant concepts is provided in Table 4.5. As shown in the table, she included more concepts related to a canonical explanation of the water-force phenomenon in her final drawing compared with her first drawing. She also included some of the new concepts from her drawing in her written explanation. She included 6 out of the 11 coded concepts (see Table 3.11) in her final drawing, compared to 2 out of 11 concepts in her first drawing. In her written explanation, she included four of the coded concepts. She also discussed what she had learned from the series of lessons in her interview at the end of the semester.

But I think I learned more about attraction and adhesion. I hadn't really heard of ... Well, I'd heard of the term attraction obviously, with positive and negative charges. But I hadn't heard of force adhesion or cohesion before. Or if I had, it was really quick, and I forgot. So that was definitely something new that I found, and the activities made me see it in different ways. I really liked the penny activity, with the water droplets. I felt like that helped show what adhesion and cohesion are a lot.

Although Eileen thought she had acquired SK regarding intermolecular water forces during the semester, she recognized that her understanding was still developing. When discussing her SK about force and motion, she responded,

I do think it developed over the semester. I'm still not entirely sure if everything I drew on the right, for the space molecules, or not the space molecules, for the water molecules in space, is correct. Because I don't think that we fully went over it at the end of class, which might have been your point in not doing that.
### Table 4.5

*Concepts Included in Eileen’s Drawings and Written Explanation for Water-Force Phenomenon*

<table>
<thead>
<tr>
<th>Big Idea Concept</th>
<th>First Drawing</th>
<th>Final Drawing</th>
<th>Written Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>All matter in the Universe is made of very small particles</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Molecular structure of water</td>
<td>○</td>
<td>●</td>
<td>○</td>
</tr>
<tr>
<td>Molecular charge (water polarity)</td>
<td>○</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Particle model for matter</td>
<td>●</td>
<td>●</td>
<td>○</td>
</tr>
<tr>
<td>States of matter</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td><strong>Objects can affect other objects at a distance</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gravity</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Magnetism</td>
<td>○</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td><strong>Changing the movement of an object requires a net force to be acting on it</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adhesion</td>
<td>○</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Cohesion</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Compression force</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Drag force on water droplets</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Unbalanced vs balanced forces</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

*Note:* Relevant science concepts to explain the behavior of water being wrung from a washcloth in space versus on earth are based on the Big Idea Tree shown in Figure 3.2

Eileen attributed drawing-to-reason with challenging her to think about what she really understood about the underlying concepts that would explain the phenomenon. As discussed in
the section on her learning outcomes based on affective characteristics, Eileen had commented during her interview,

So I think drawing pushed my thinking deeper. Because I do think with writing, that sometimes you're able to ... I think it's easier for me to put my thinking in words. But also, sometimes you're able to write around the question a little bit. You can't really do that when you're drawing.

While Eileen included several of the forces acting on the water molecules on earth and in space (Table 4.5), like Avery, she did not draw or write about them in terms of their relative magnitude or as a system of forces acting on water. This was consistent with her interview in which Eileen discussed different forces that were evident in the phenomenon, but not necessarily as a system of forces acting of the water molecule to result in motion. For example, she seemed to focus on the process of magnetism for why the water behaved differently in space versus on earth, stating that “ then I made a guess, or a prediction about how maybe the wash cloth in space, because if something has a positive charge, since the water molecules have the negative charge, maybe that's why they're sticking to each other.” Therefore, the concept of unbalanced versus balanced forces was not coded in the content analysis as new conceptual knowledge in either her drawings or her written explanation.

A couple of interesting and unique aspects of Eileen’s drawings related to her developing understanding of the structure of liquid water in space. When drawing the layer of water on the washcloth in space, she initially drew separate, disconnected spheres to represent liquid water (Figure 4.16). After a question from the instructor probing her thinking about this representation of water, she revised the drawing to have a continuous layer of spherical drops surrounding the washcloth in space (Figure 4.17). During the interview, she also referred to water on the
washcloth as droplets versus a layer of liquid, stating “I talked about how there was force adhesion, making the water droplets stick onto the wash cloth,” when summarizing what revisions she had made to her drawing versions. She also conceptualized liquid water as having a greater density in space, since in her magnification tools she represented liquid water having particles that were space further apart on earth compared to space (Figures 4.16 & 4.17). When asked about what informed changes that she made to her drawings, Eileen responded,

But for the space one, other than knowing that there is not gravity in space, I wasn't really sure why the water droplets stayed together. I figured it might ... I still had them drawn close together in the magnifying glass, because I had the understanding about how the molecules being closer together represents a solid. So I knew that it looked kind of like a gel.

She also confirmed that she had intentionally drawing the dots closer together in the magnification tool in space versus on earth to reflect her idea that liquid water had a different spatial structure due to her developing understanding about the magnitude of gravitational force in space.

**Science drawing.** As discussed previously with Avery’s SK learning outcomes related to the practice of drawing-to-reason, Eileen’s series of drawings (Figures 4.15 to 4.17) were analyzed for *three aspects of model use*, including a) *model relationships*, b) *purpose and salient features*, and c) *metacognition* (see Figures 3.15 to 3.17; Table 3.14). The operationalized measures for *model relationships* were the types of translations included in the drawings (Figure 3.15). For *purpose and salient features*, the operationalized measures were inclusion of foundational images and scale tools in drawings, frequency of text for explanation versus labeling in drawings, and inclusion of non-observable structures, processes and
relationships versus observable features in drawings (Figure 3.16). **Metacognition** was operationalized based on the frequency of revisions based on type in their drawings (Figure 3.17).

The three aspects of model use were categorized as novice versus more expert based on criteria outlined in Quillin and Thomas (2015) and to reflect Eileen’s developing use of drawings as a tool for reasoning. The use of the term novice was not meant to imply a lack of value for other ways that drawing supports learning in science (Ainsworth et al., 2011). As shown in Figure 4.10 and described in Chapter Two, Ainsworth et al. (2011) outlined other valuable purposes of drawing, including drawing-to-learn, drawing-to-communicate, drawing-to-engage, and drawing-to-represent (Figure 4.10). These purposes range from a product-oriented focus on the final drawing to a process-oriented focus on the generation of the drawing. While Eileen’s drawing-to-reason may have been novice or more expert based on the model-use aspects, she may have displayed or recognized other important uses for drawing in science during the course, which will be pointed out in the discussion of the coding for aspects of model use from her drawings and from her interviews.

For **model relationships**, which was operationalized based on the inclusion of different types of translations in her drawings, Eileen displayed a more expert use of drawing-to-reason as the series of lessons with explicit instruction progressed (Table 4.6). As she revised her drawings, she included a greater variety of translations, likely reflecting modeled examples included by the instructor during the explicit instruction (Table 3.2).

In her Cartesian diver drawing (Figure 4.15), Eileen only included visual-text translations, which was used for textual and visual representations of observable features for the phenomenon. She did not include a visual-text translation for non-observable structures,
processes or relationships in her Cartesian diver drawing. However, for her series of water-force drawings, she included a greater variety of translations as she revised her drawings. She used vertical translations in the first version of the water-force phenomenon drawing to show the particle structure of liquid water. With later drawing versions, she used vertical translations to show the structural properties of water molecules, the bipolar charge of water molecules, and the adhesion force of water molecules to the washcloth on earth. In later drawing versions (Figure 4.17), she included a horizontal translation to represent water molecules both as dots in the particle model and as a ball-and-stick model.

**Table 4.6**

*Types of Translations in Eileen’s Drawings of Science Phenomena*

<table>
<thead>
<tr>
<th>Drawing</th>
<th>Visual-Text</th>
<th>Horizontal</th>
<th>Vertical</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Spatial</td>
</tr>
<tr>
<td>Cartesian diver</td>
<td>●</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td><em>Water-force phenomenon drawing version</em></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1st</td>
<td>●</td>
<td>○</td>
<td>●</td>
</tr>
<tr>
<td>2nd</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>3rd</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Final</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
</tbody>
</table>

*Note.* In the table inclusion the type of translation is indicated by ●, while no evidence of the translation type is shown by ○.

Based on the *three operationalized measures* for the *purpose and salient features* aspect of model use, Eileen also displayed more expert use of drawing-to-reason after explicit instruction during the series of lessons. Her use of *foundational images and scale tools* in both the Cartesian diver and water-force phenomenon drawings is shown in Table 4.7. The *purpose of*
The inclusion of textual representations for labels versus explanations in the drawings is shown in Figure 4.21. A graph of her inclusion of non-observable structures, processes, and relationships versus observable features in her series of water-force phenomenon drawings is shown in Figure 4.22. Only the drawing versions of the water-force phenomenon were included in Figure 4.22, because the concepts for the Cartesian diver were different than for the water-force phenomenon, and therefore, were not a useful comparison.

The first operationalized measure for purpose and salient features, was the inclusion of distinct examples of the foundational images and scale tools in drawings. These graphic symbols (Figure 3.4) were introduced and modeled by the instructor as part of the explicit instruction on drawing to reason (Table 3.2). Eileen used frames and vectors (Table 4.7) in her drawings for both the Cartesian diver (Figure 4.15) and the water-force phenomenon (Figures 4.16 & 4.17). Eileen used verticals lines in her Cartesian diver drawing to represent a temporal sequence and folded the paper in half to denote location differences for the water-force drawings.

Similar to the other PSTs, Eileen’s inclusion of framing in her drawings for both phenomena likely reflected the instructor-modeled framing included in the lesson as the PSTs began to generate their own drawings for the Cartesian diver. While the other foundational images and tools were projected in the classroom as the PSTs were drawing, their use in drawings was not modeled until after the PSTs generated their Cartesian diver drawing to avoid influencing what observable versus non-observable features the PSTs included. Eileen’s use of vectors in all her drawings may have reflected her familiarity with their use from her physics class or other science-oriented courses. While Eileen did not specifically discuss where she had learned to use vectors as visual representations in her drawing, the other PSTs mentioned that
they had exposure to drawing force diagrams during their requisite physics course as part of their undergraduate education program.

Table 4.7

_Eileen’s Use of Foundational Images and Scale Tools in Drawings_

<table>
<thead>
<tr>
<th>Drawing</th>
<th>Frames</th>
<th>Magnification Tool</th>
<th>Particle Model</th>
<th>Vectors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Structure</td>
<td>Process</td>
<td>Force</td>
</tr>
<tr>
<td>Cartesian diver</td>
<td>●</td>
<td>○</td>
<td>○</td>
<td>●</td>
</tr>
<tr>
<td>Water-force phenomenon drawing version</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1st</td>
<td>●</td>
<td>●</td>
<td>○</td>
<td>●</td>
</tr>
<tr>
<td>2nd</td>
<td>●</td>
<td>●</td>
<td>○</td>
<td>●</td>
</tr>
<tr>
<td>3rd</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Final</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
</tbody>
</table>

*Note.* Within the table, inclusion the type of translation is indicated by ●, while no evidence of the translation type is shown by ○.

In her water-force drawings, Eileen incorporated other foundational images and scale tools, including the magnification tool to draw the structure of water molecules and the process of adhesion, and the particle model to show that visible water is composed of non-observable molecules and their spatial relationship. Inclusion of the magnification tool, particle model, and vectors was modeled explicitly by the instructor after the PSTs generated their Cartesian diver drawings, which may have influenced Eileen’s incorporation in her water-force phenomenon drawings. During her interview, she commented that she had “learned to do [the magnification tool] in [the methods] class” and that she “might have seen it before, but [she didn’t] think [she] would have thought to use it.”
The second operationalized measure for purpose and salient features was the purpose of textual representations included in drawings. Eileen’s use of text also changed during the series of lessons on drawing-to-reason (Figure 4.21).

Figure 4.21

Eileen’s Inclusion of Text in Drawings to Explain Science Phenomena

![Graph showing frequency of text in drawings](image)

*Note.* Text phrases were counted as based on their use as a label or as an explanation in the drawings (Table 3.13). Frequency is defined as the total number of occurrences for each category of text in a drawing. The sequential drawing versions for explanation of the water-force phenomenon are referenced as 1st, 2nd, 3rd, and final water phenomenon.
In her Cartesian diver drawing (Figure 4.15), the purpose of all text in the drawing was labeling. While she still included text for labeling in her first drawing version for the water-force phenomenon (Figure 4.16), a greater frequency of the included text was used for an explanatory purpose. For example, she explained her idea for the difference in spatial proximity of water molecules in the liquid form in space versus on earth.

Her inclusion of text for labels and for explanations increased as she included more non-observable structures, processes and relationships in her water-force drawings. In contrast to Avery, Eileen included visual representations along with explanatory text, for new ideas that she incorporated in her water-force drawings after each lesson, which suggests a more process-oriented use of drawing. In addition, Eileen did not discuss her prior science methods’ course focus on drawing and labeling accurately during her interview, which would have suggested a more product-oriented use of drawing.

The third operationalized measure for the purpose and salient features aspect of model use was the inclusion of non-observable structures, processes, and relationships versus observable features (Figure 4.22). While Eileen included more observable features compared to non-observable structures, processes, and relationships in her first drawing for the water-force phenomenon, she focused on adding more salient features in her subsequent drawing versions. Similar to the other PSTs, Eileen’s third and final drawing versions appeared to include the same concepts, so there was no change in the inclusion of non-observable versus observable features.
Figure 4.22

*Eileen’s Inclusion of Observable versus Non-observable Features in Drawings*

*Note.* The drawing version on the x-axis refers to the phenomenon of wringing water from a washcloth in space versus on earth. The frequency on the y-axis refers to the total number of different observable features (Table 3.12) or non-observable structures, processes, and relationships (Table 3.11) coded in each drawing. There was a maximum of 8 distinct observable features and 11 distinct non-observable structures, processes and relationships used. The included representation of the observable features and non-observable structures, processes, and relationships could be either textual or visual in the drawing.
**Metacognition** was the last aspect of model use that was evaluated by deductively coding for types of revisions or questions (Figure 3.17) in the PSTs’ series of water-force phenomenon drawings. The revisions to drawings were categorized as being based on content from the lesson activities (content revisions) or prompted by instructor feedback on the drawings (prompted revisions). The questions were ideas or information about which PSTs indicated they still wondered in their drawings. The frequency of revisions and questions included in Eileen’s series of water-force phenomenon drawings are shown in Figure 4.23.

**Figure 4.23**

*Eileen Operationalized Measures of Model Use Based on Metacognition*

![Graph showing revisions and questions](image)

*Note.* Prompted revisions are changes in PSTs’ drawings due to an instructor prompt. Content revisions are changes based on lesson content. Questions are things that PSTs indicated they still wondered about in their drawings. Frequency on the x-axis is the total number revisions or questions in a drawing. The sequential drawing versions for explanation of the water-force phenomenon are referenced as 1st, 2nd, 3rd, and final on the y-axis.
Her instructor-prompted revisions included drawing a continuous layer of spherical droplets around the washcloth in space and indicating that there was a thin layer of water surrounding the washcloth on earth. The rest of her revisions were ideas that were added based on the lesson content. In her interview, Eileen discussed how the revisions to her drawings were based on the lesson activities.

Yeah. I think on this one, with the water in space, I talked about how there was force adhesion, making the water droplets stick onto the wash cloth. Which also came from us learning about that in class. I'm not sure exactly which activity that was though.

While her revisions to her drawing contained content from the series of lessons, they also appeared to be external visualizations of her tentative ideas, which were still developing and not necessarily aligned with canonical explanations for the phenomenon. Her lingering question was her uncertainty about whether there was a spatial difference between water molecules in liquid water in space versus on earth. While observing the video of the washcloth being wrung out in space, she had noticed the physical appearance of the water on the washcloth reminded her of a gel structure, which she noted in her drawing (Figure 4.16). She proposed the water molecules were closer together in water in space rather than on earth because of the difference in gravitational force. Her inference was based on her background knowledge regarding states of matter, including that solids maintain their shapes and that in general, molecules are arranged more compactly in solids compared to liquids. During her interview, she discussed her uncertainty and the basis of her idea.

But for the space one, other than knowing that there is not gravity in space, I wasn't really sure why the water droplets stayed together. I figured it might ... I still had them drawn close together in the magnifying glass, because I had the understanding about how the
molecules being closer together represents a solid. So I knew that it looked kind of like a gel. But I feel like on this one, I just showed what I could see, or try to piece together what was happening.

While these ideas do not align with canonical science explanations, they are an example of Eileen using her drawing to think through her developing ideas, which is a process-oriented use of drawing. Eileen discussed in her interview that,

I'm still not entirely sure if everything I drew on the right, for the space molecules, or not the space molecules, for the water molecules in space, is correct. Because I don't think that we fully went over it at the end of class, which might have been your point in not doing that.

Eileen seemed to be metacognitively aware of both her SK and her drawing knowledge throughout the series of lessons, based on both the deductive coding of her drawings and her comments during class and in her interview. For example, during the first lesson before drawing her Cartesian diver explanation, she shared that she was unsure of what to draw. In addition, although Eileen did not include as many ideas in her drawings as Joan or Reece, Eileen appeared to have had a process-oriented use of drawing. She frequently used the word “think” or “thinking” in her interview about her drawing. She also discussed her how she changed her attitude about the value of drawing, stating that “…now I feel like it does help me learn, and also see what I understand or don't understand a little more.”

In summary for the drawings during the series of lessons with explicit instruction, Eileen overall developed a more expert use of drawing-to-reason based on the three model use aspects. For model relationships, she demonstrated more expert use that was evidenced by the increased types of translations she included in her drawings as the lessons progressed. For purpose and
salient features, she demonstrated more expert use by incorporating more types of foundational images and scale tools, including more non-observable structures, processes, and relationships to explain the water-force phenomenon, and using textual representations for explanations, in addition to labels, as she revised her drawings. The measures for metacognition also suggested a more process-oriented use of drawing.

**Eileen’s PCK Learning Outcomes**

PCK was the final learning outcome of interest for the science methods course with explicit instruction on drawing-to-reason. The PSTs’ lesson plans and their interview discussions of facilitating their lessons were the primary data used to explore how their incorporation of drawing as an instructional strategy would support their students’ use of drawing. As mentioned in Chapter Three for the methodology, the data to explore this learning outcome was more limited due to constraints in the field experiences such as time in a single semester for planning and facilitating their own science lessons and the limited availability of the field mentor teachers for coordination of the science methods course activities due to their classroom responsibilities and schedule. The incorporation of drawing in the lesson plans and interview responses was deductively coded (Table 3.15) based on whether it would support elementary students’ novice versus more expert model use of drawing-to-reason. The coding was based on the three model aspects, including model relationships, purpose and salient features, and metacognition, which were used to explore how the PSTs used drawing for their own SK learning. Analysis of Eileen’s lesson plans from the first and second field experience weeks are shown in Table 4.8.

As discussed in the subsection about her field experience, Eileen used the probe “Cookie Crumbles” (Keeley et al., 2005) in her first week’s lesson. She did provide scratch paper for the students in case they wanted to think through their ideas by drawing, but did not provide explicit
guidance for the drawing or intentionally incorporate the drawings as part of the group discussions. Therefore, the **purpose** for including drawing in her first lesson was consistent with encouraging students to use it as a tool for reasoning, which would help them develop more expert modeling use of drawing. However, it would not support development of more expert use based on **model relationships** because there was not an intentional focus or practice with multiple modes of representation or opportunities for students compare different visual representations of science ideas. In addition, the optional inclusion of drawing would not support more expert **metacognitive** use of drawing as a tool to reason since the lesson did not include explicit drawing guidance or an opportunity to evaluate and revise science ideas or drawing quality based on clarity of the drawn explanation.

In her second field experience week, Eileen also included drawing in her lesson for the “Cloud in a Bottle” phenomenon (Science World, n.d.) in ways that would support her student’s more expert use of drawing-to-reason. For supporting more expert use based on **model relationships**, she was intentional about having all the students draw their observations and explanations for the phenomenon, which were included in small group discussions. Therefore, students would have the opportunity to compare and discuss multiple models of the phenomenon. She supported a more expert model use based on the **purpose and salient features** of drawing by including questions to encourage students to draw non-observable structures, processes and relationships, such as “Why do you think the cloud formed after the stopper was removed?” and “What might have caused that change you observed?” Her use of a graphic organizer supported both the model aspects of **purpose and salient features** and **metacognition**. Having the bottle shape already printed allowed students to focus more on expressing ideas about what was causing the observed cloud versus drawing the observable bottle. In addition, it would
help students focus on a comparison of their ideas during their group discussions versus differences in the drawn observables, which would help them metacognitively evaluate and revise their initial drawings. While she had limited instructional time during the lesson to include explicit instruction on visual literacy interventions, Eileen shared during her interview that she had modeled the use of vectors, which the students incorporated in their drawings. Eileen commented during her interview that she would have liked to include more drawing instruction during her second field week lesson on the “Cloud in a Bottle” phenomenon (Science World, n.d.), because she thought it “could have been helpful to show.”

Table 4.8

_Eileen’s Incorporation of Drawing in Her Field Experience Lesson Plans_

<table>
<thead>
<tr>
<th>Field Experience Lesson Plan</th>
<th>Model Use Aspects</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Model Relationships</td>
</tr>
<tr>
<td>Week One: Page Keeley Probe</td>
<td>○</td>
</tr>
<tr>
<td>Week Two: Discrepant Event</td>
<td>●</td>
</tr>
</tbody>
</table>

\(\bigcirc = \text{No drawing}; \bigcirc = \text{Novice}; \bigblacklozenge = \text{More Expert}\)

*Note.* Symbols in tables indicate results from coding for how PSTs’ planned instruction would be anticipated to support elementary students’ use of drawing as the science practice of modeling based on the aspects of model relationships, purpose and salient features, and metacognition (Table 3.15).

As a teacher, Eileen used her students’ drawings for the “Cloud in a Bottle” phenomenon to assess their understanding and to reflect on what concepts might be important to focus on in
future lessons. In her interview she shared her views about the value of supporting students to include non-observable structures, processes, and relationships in their drawings.

I think [drawings] can influence me to see how deep a student understands the concept. Because if they just drew, for the cloud in the bottle for example, the rubbing alcohol at the bottom, or just some swirls to represent the gas, and labeled that, I know what they see. But for the students who incorporated something about air temperature or pressure, which wasn't that many of them. But for the ones who did, I can tell that they have either a deeper understanding of what was happening, or at least they were trying to make those connections. Some of them weren't necessarily correct in what they put down, but I can see they were trying to think of the reason behind why the science was happening.

Eileen also shared that even the student ideas that did not align with canonical science explanations for phenomenon were valuable for her as a teacher. When asked if students’ incorrect ideas in drawings were useful, she said,

Yes, I do. Because it still tells you that they're moving past the point of just understanding what they see in front of you. Then since you know that they're incorrect, you can help correct them. Whereas if you didn't know if they were incorrect or correct, you wouldn't know that you needed to help get them to that correct point of understanding.

The drawing-to-reason instructional interventions during the science methods course guided how Eileen included drawing in her own teaching practice. She shared during her interview, that she had modeled the inclusion of drawing in her instruction based on the different instructional interventions from the science methods course. When discussing her lesson plan for the second field experience week, she shared,
This was another one where we did pull in drawing. So all the resources about drawing that we had learned. We had a graphic organizer for them, with a model of the bottle, and the stopper on top. Which, we should have adjusted that a little bit for the after portion. But we had them draw what was happening before we pulled the stopper out, and then after we pulled the stopper out, I'm pretty sure. We asked them questions about that, like, "What could you add to your drawing of the event, to represent what was happening?"

She also recognized other valuable purposes for inclusion of drawing in science instruction (Ainsworth et al., 2011) when she reflected on the lesson, including drawing-to-engage.

But one thing that I realized when I was doing the “Cloud in the Bottle” with the students is, having them draw what they see happening while the experiment was going on helped to focus their attention so much. It helped them pay attention, because it gave them something to do. They found it a little more exciting too, than just having to write out their thoughts. We did have them write later on. But it was more exciting in the moment.

**Summary of Eileen’s Learning Outcomes**

This section of Chapter 4 described Eileen’s learning outcomes based on affective characteristics, SK, and PCK, which all appeared to have changed during the science methods course that incorporated explicit instruction on drawing-to-reason.

Both the quantitative and qualitative data strands indicated changes in Eileen’s affective characteristics towards drawing and teaching during the semester. While Eileen expressed a more negative attitude towards drawing at the beginning of the semester, by the end of the semester, her attitude was slightly more positive, particularly for the set of adjectives that Bauer (2008) attributed to emotional satisfaction. While the factors evaluated in the SDA showed a small change to a more positive attitude, her interviews supported more positive attitude, value,
self efficacy and interest towards drawing. In particular, she discussed recognizing the value of
drawing both for her own learning and for science teaching. Her STEB was also more positive at
the end of the semester compared to the beginning. In general, her attitude towards physical
science, which was neutral to more positive, did not change during the semester, but the SDA
factor that Bauer (2008) attributed to intellectual accessibility was slightly more negative. This
was consistent with Eileen’s discussion about her SK during her end-of-semester interview.
However, she expressed that during her teaching career she could continue to build her
knowledge about physical science.

She also acquired SK about intermolecular water forces during the semester based on the
analysis of her drawings and written explanation. The operationalized measures for model
relationships, purpose and salient features, and metacognition, indicated that Eileen also
developed more expert model use of drawing-to-reason over the series of lessons with explicit
instruction on drawing-to-reason. Both the deductive analysis of her drawings and her interview
responses showed evidence that she used drawing as a thinking tool.

Analysis of Eileen’s lesson plans and her interview responses supported PCK learning
outcomes regarding drawing as an instructional strategy in science. While Eileen included
drawing in science lessons for both field experience weeks, Eileen incorporated drawing in more
ways that would support elementary students developing more expert model use of drawing
during the second field experience week after explicit instruction on drawing-to-reason in the
methods course. For example, she incorporated graphic organizers and questions to help students
focus on drawing non-observable features versus the observable details, included limited visual
literacy instructional interventions, and used student-generated drawings as the focus of small
group discussions. Similar to Avery, her allotted science instructional time during her field
experience weeks may have limited the drawing interventions that Eileen included in her own instruction. In addition, she recognized other valuable science instructional purposes for drawing, such as the engagement of students, when she discussed incorporating drawing into her future science lessons.

**Joan**

Throughout the spring semester, Joan exhibited quiet confidence as a student in the methods course and as a teacher in her field experiences. As described for the other PSTs, Joan was typically active and engaged in class and exhibited interest in the lesson content. The course included several phenomenon demostrations, in addition to the Cartesian diver and the washcloth wringing demonstration, and Joan contributed ideas to the discussion, particularly when she appeared to feel confident in her answer. If there were omissions or corrections needed to assignments, she was open to feedback and incorporated suggestions to improve subsequent submissions of assignments. Her confidence as a teacher was evident in her assigned teaching reflections. Similar to Avery, she expressed feeling comfortable and excited about leading her lessons in the field. She even stated how much fun she had thinking about the different ways students might answer questions she included in the lesson and how comfortable she felt during the lesson. Overall academically she was a strong student, and her scores on assessed assignments were in the 95th percentile of awarded grades.

**Initial Science Epistemological Beliefs**

In the Keeley’s (2010) probe “Doing Science” (Figure 4.2) Joan indicated that she most agreed with Antoine’s statement that “I think scientists just try out different things until something works.” Joan stated that she agreed with Antoine because “I view science as an explorative subject with no right or wrong way of answering a question.” (Joan, Probe Response,
Jan. 24, 2022). While Joan selected Antoine, her responses about why she disagreed with the other probe choices indicates that she also partially agreed with Marcos, because she did not think that scientists used a prescribed process for building knowledge.

I disagree with Tamara because although the scientific method exists, I think science is more fluid and there's not a definite set of steps scientists are supposed to follow. I disagree with Marcos not because I think it's wrong, I just like the wording of Antoine's explanation better. I disagree with Erin because not every science exploration deals with experimentation. I think exploration is a better word to use. (Joan, Probe Response, Jan. 24, 2022).

Joan’s use of the term exploration conveyed an impression of scientists as curious and seeking versus all-knowing and authoritarian. She was the only PST who included epistemological views on the nature of science knowledge in her explanation of her probe choice. Her reasoning suggested an interpretivist view of science knowledge as provisional and cumulative versus permanent and fixed. In addition, her epistemological views of the source of science knowledge was also more interpretivist, since she recognized that experiments are not the only forms of inquiry activities that scientists use to answer their questions. However, Joan did not recognize that while scientists do not use a prescriptive process for investigations, they are methodical in their approach to building and justifying knowledge.

**Field Experience Lessons**

For her field experience during the semester, Joan was assigned to a 5th-grade classroom. Because of the grade level to which she was assigned, she had the opportunity to observe more classroom instruction of science compared to the other three PSTs in this study. Joan and her PST field partner selected the formative assessment probe “Human Body” (Keeley, 2011) for their
first lesson. They selected the probe based on their field teacher’s guidance on content that would be consistent with her lessons on the structure and systems of organisms from the fifth grade life science standards from the North Carolina Course of Study (NCDPI, 2021b). The “Human Body” probe elicited students ideas about the cellular makeup of the body and included choices that reflect an understanding that all parts of the body are composed of cells even the skin and internal organs. Elementary students often think of the body as a vessel with a film or outer surface that holds the inner contents. They do not necessarily think of skin as being composed of cells as part of the integumentary system or of organs as a collection of cells.

For her second field experience week, Joan chose to use the demonstration “Blobs in a Bottle” from the Science Bob website (Science Bob, n.d.). Her chosen phenomenon was consistent with fifth grade physical science standards from the North Carolina Course of Study (NCDPI, 2021b) regarding properties and change of matter. Joan’s mentor teacher was leading a weather unit during the time period of the second field experience week, which incorporated the physical standards on properties and change of matter, along with the earth science standards on weather. The “Blobs in a Bottle” demonstration used water, oil, food coloring, and an Alka Setzer tablet to create a lava lamp-like object with colored water spheres cycling between floating and sinking in an oil layer due to buoyant force from carbon dioxide bubbles created from a chemical reaction and the hydrophobicity and lower density of oil. The phenomenon built knowledge about the concepts of density, solubility, chemical changes, buoyancy, and balance versus unbalanced forces. Since Joan only had 35 minutes for the lesson, her questions for the students focused mainly on the chemical changes based on the probing questions she included about the effects of temperature and size of the Alka Setzer tablet. However, in her reflection for this lesson, she included ideas for a follow-up series of lesson to build knowledge about the other
related concepts, which would be needed to make meaning about the “Blob in a Bottle” phenomenon.

**Force and Motion Knowledge**

Regarding general knowledge on force and motion, Joan appeared to be one of the PSTs with a stronger SK foundation based on correct responses on the ATLAST Force and Motion assessment (Horizons Research Inc., 2011). Her percentage of correct responses at the beginning and end of the semester were higher than or the same as the group median, respectively (Figure 4.24). The change in responses from the beginning to end of the semester likely represents variability between testing occasions since the retest reliability was 0.88 (Horizons Research Inc., 2011).

Similar to Avery and Eileen, Joan scored at least one correct on all the force and motion sub-ideas included in the assessment (Appendix A) with the exception of sub-idea E that if an object is moving faster and faster, then there is a net force acting on the object in the same direction as the motion. Consistent with the other PSTs, she also exhibited all three types of knowledge that were assessed by the instrument (see Appendix A), which Horizons Research Inc. (2011) categorized as content knowledge, knowledge use to analyze/diagnose student thinking, and knowledge use for instructional decisions.
Figure 4.24

Joan’s ATLAST Force and Motion Responses Compared to the PSTs’ Group Median

Note. Joan’s correct responses at the beginning (blue bar) and end of the semester (orange bar) compared with the median for all four PSTs (gray line). Based on the guidelines for use of the ATLAST Force & Motion Teacher Assessment (Horizon Research, Inc, 2011) the specific values are not listed. The bars are plotted with the median line to provide qualitative information for Avery’s general knowledge about force and motion relative to the other PSTs.

Science Drawings of Force-related Phenomena

Joan’s drawings from the semester are shown in Figures 4.25 to 4.27, including her drawing to explain the Cartesian diver phenomenon (Figure 4.25), her first drawing for her water-force phenomenon on the second week of the series of lessons with explicit instruction on drawing-to-reason (Figure 4.26), and her final drawing for the water-force phenomenon (Figure
4.27). The description of the drawings here will mainly focus on qualitative description, and a more detailed analysis based on the coding scheme outlined in the methodology will be presented below for the SK learning outcomes.

Joan divided the horizontal space for her Cartesian diver drawing (Figure 4.25) into thirds with vertical lines to create temporal frames of before, during, and after the application of force on the bottle. This reflected the visual literacy instruction in the class lesson prior to the Cartesian diver demonstration, as well as emphasis and modeling on how to create temporal frames by the instructor immediately prior to generation of the drawings. Like Avery and Reece, Joan’s visual images encompassed most of the vertical and horizontal space on the paper. The pencil markings for both her drawn images and included text were bold, which along with the size of her drawings suggested confidence in her knowledge about the underlying causal explanation for the phenomenon.

In addition, during the process of drawing her Cartesian diver explanation, Joan discussed the benefit of a graphic organizer with represented bottles with the instructor, so that students could focus on drawing their ideas versus focusing on the observable objects. She commented it would be useful to facilitate her focusing on her ideas versus repeatedly illustrating the bottle. She possibly was already thinking about how to scaffold students to focus on more salient features in their drawings. However, in her interview, she commented “when I was in high school, my teachers would ask me to [draw] and I would hate it because it was kind of boring,” therefore, she may have also been thinking about how to best engage students with the practice in the classroom.
Figure 4.25

Joan’s Cartesian diver Drawing

- **Before**: Air trapped & freezing in bottle
- **During**: Hand squeezing + applied pressure
  - Force from hand pushes dropper inward
  - Air from dropper is squeezed out
  - Weight bringing the diver down
- **After**: Moves back up
Figure 4.26

Joan’s First Drawing for Water-Force Phenomenon
Figure 4.27

Joan’s Final Drawing for Water-Force Phenomenon
Like Avery, Joan included the air space at the top of the bottle but did not represent it changing in volume in the sequence of frames. The wavy line indicating the top of the water was at the same height in all three frames. An additional detail that Joan included, which the other PSTs did not, was air trapped inside the diver. She drew the air as a sphere inside the top of the diver in the before frame and in the after frame. For the middle frame, she did not include air in the stopper, because part of her explanation was that the force from hands squeezing the outside of the bottle also compressed the diver and caused the water to be expelled from it.

In addition to frames, the only other foundational image or scale tool that Joan used in her Cartesian diver drawing was the vector. In the middle frame, Joan drew straight arrows directed inward to represent the force of hands pushing on the bottle and included small arrows directed inward to represent her that the applied force from the hands caused the water to push inward on both sides of the diver. She drew the bottle and the diver in the middle frames as being distorted in the middle from the force. In the middle frame, a straight vector also was used to represent the downward movement of the diver due to the load, and in the last frame, to represent the upward movement of the diver when air returned after the hands released the bottle. Joan also used small, curved vectors in the middle frame to illustrate air being pushed out of the diver as it is squeezed. In the Cartesian diver drawing, Joan used several ways to associate the included textual representations to the visual images. In some instances, she used a line to indexically link a feature with a label or explanation. She also used an arrow for the same purpose, as well as just placing the text near the associated visual image.

In her first drawing of the water-force phenomenon (Figure 4.26), Joan included more non-observable structures, processes, and relationships along with observable features. Consistent with her Cartesian diver drawing (Figure 4.25), she included framing, but used a
spatial comparison of earth versus outer space instead of the temporal framing. Unlike the framing for the Cartesian diver, Joan did not draw a vertical line to divide the horizontal space, but instead folded the paper to create a crease. The orientation of images in her drawing was horizontal, with her images and text filling most of the space in both frames. Vertically the images were aligned towards the top of the page, with the first drawing (Figure 4.26) filling approximately the top third of the space, and the final drawing (Figure 4.27) filling three quarters of the space. In her drawings, the labels, lines, and shapes were drawn with bold, thick lines. The features that Joan drew to represent her explanatory ideas about the water phenomenon were slightly bolder and darker than the washcloth, and therefore, appeared to be foregrounded in the drawings. In contrast to Avery, besides the framing of earth and space, there did not appear to be any particular organization for the drawn ideas or included text. The text was a variety of sizes and orientations throughout the drawing. While Joan was similar to Avery and included text for explanation of her latest ideas, she also drew images that accompanied the text. For example, in her first and final drawings (Figures 4.26 & 4.27) she wrote about liquids conforming to the shape of their containers, but also included drawn examples of water in a glass, bowl and bottle to represent the idea visually.

The washcloths on both earth and in space were drawn as long oval shapes outlined by a single wavy line, which reflects the soft material of the washcloth. The washcloth in space was drawn larger and at a higher vertical alignment than the washcloth on earth. The magnification scale tool was used to provide a close-up representation of the washcloth fibers. The washcloth was labeled on earth with a straight line connecting the text to the image, while in the space frame the text was written above the right upper corner of the drawn washcloth.
There were a couple of noteworthy attributes of Joan’s drawings of the water-force phenomenon (Figures 4.26 & 4.27), compared with the other PSTs. One is variety of ideas included as her drawings progressed as seen in her final drawing (Figure 4.27). As mentioned above, she included the greatest variety of ideas in her drawings; some related to the lesson content from class, but others represent prior knowledge she was incorporating. For example, while the other PSTs drew the spatial and structural properties of water, Joan also included the information about liquid water conforming to its container. She and Reece both drew the magnified structure of the washcloth to contrast with the spatial arrangement of water molecules in the liquid state, but Joan included a magnified view of water molecules interspersed between the fibers of the washcloth on earth versus the fibers with no water molecules in space. Other ideas included how the make-up of the earth’s atmosphere versus space may affect attraction from charges, and the potential electrostatic charges on individuals affecting adhesion of water molecules. She also included representations of the class activity that explored cohesion and adhesion by placing water droplets on the face of a penny.

Like the other PSTs, Joan’s representations of visible water in her drawings varied and included textual representation and visual representations of liquid on the washcloth, which differed on earth versus in space, and tear-shaped droplets. On earth, Joan drew water droplets forming at the bottom of the washcloth and the magnification scale tool with water particles interspersed on the washcloth fibers to represent water filling spaces between the fibers of the washcloth. Unlike the other PSTs, she did not represent either with shading of the space or markings if there was a visible layer of water on the outside of the washcloth in addition to filling spaces between the fibers. In space, Joan represented the water film on the washcloth as a thick, wavy layer around the outside of the elongated oval representing the washcloth. She also
used the magnification tool to show there were no water particles between the fibers of the washcloth in space and to show the water layer was composed of smaller particles that were water molecules. Joan also drew other visual representations of visible water, including the wavy layers of water around the stick figure and hand when representing her ideas about electrostatic charge attracting water molecules and the dome of water on top of the penny in her final drawing (Figure 4.27).

Joan also incorporated more of the foundational images and scale tools (Figure 3.4) in her drawings of the water-force phenomenon (Figures 4.26 & 4.27) compared to her Cartesian diver drawing (Figure 4.25). In the drawings for the water-force phenomenon, vectors were used to represent direction and force. Vector shape and direction represented distinct types and direction of force. For the compression force from wringing the washcloth, Joan at first drew straight arrows pointing inward on either end of the washcloth (Figure 4.26), but after an instructor prompt, she revised the drawings to represent the compression force all around the washcloth by used arrows spiraling around the front and back of the washcloth (Figure 4.27). For the front of the washcloth the compression force is drawn as vector with a solid line, and for the back of the washcloth a dashed line is used for the vector. Joan did not represent the forces of adhesion or cohesion with the washcloth on earth or in space, but she did include a text explanation of a force that she termed adhesion keeping the water molecules together in the layer around the washcloth. She did include a vector, but it was used to link the text explanation to the drawn water layer. Her representation of adhesion and cohesion was included in the images below the washcloth, where she drew a hand surrounded by a water layer and used the magnification scale tool to draw water molecules cohering to each other and adhering to the hand. The attraction between the molecules and to the hand are drawn as small arrows.
Joan used the magnifier scale tool in her water-force phenomenon drawings for many purposes, including the use discussed above to represent her ideas of adhesion and cohesion. The magnification tool was used to draw translations between visible water and its particle composition, between visible water and its molecular structure, and between the particle model and the molecular structure. Joan also used it to draw the fiber structure of the washcloth, to represent her idea of the negative charge of water, and to show the presence of absence of oxygen in the air. Her representations for water included the textual representation, a particle model based on the foundational images (Figure 3.4), and two-dimensional, stick-and-ball models. There were multiple versions of the stick and ball model, including unlabeled balls for the atoms, balls with the hydrogen and oxygen atoms labeled with the element symbol, and balls with the element symbol and charge. Interestingly, Joan did not use a symbolic representation of H2O for water but did use the symbolic representation for oxygen.

**Joan’s Learning Outcomes Based on Affective Characteristics**

This section synthesizes the quantitative and qualitative data strands exploring Joan’s affective characteristics during the science methods course with explicit instruction on drawing-to-reason. Note that all quotes in the following sections are from Joan’s semi-structured at the end of the semester (Joan, Interview, May 24, 2022). Because affective characteristics are targeted towards something (Anderson and Bourke, 2000), this section is organized by affective characteristics towards drawing, physical science, and science teaching.

**Drawing.** Of the four PSTs, Joan expressed the most positive attitude towards drawing at the beginning of the semester, based on the three factors of anxiety, intellectual accessibility and interest&utility, and the emotional satisfaction set of adjectives from the SDA instrument (Figure 4.28). Therefore, there was minimal to no change in her attitude over the coures of the semester
with the exception of the factor for interest & utility. This minimal change based on the SDA instrument may have been a ceiling effect from her very positive self-reported attitude at the beginning of the semester. Her attitude may have been influence by positive experiences with drawing during her physics course during her sophomore year.

**Figure 4.28**

*Joan’s Attitude Towards Drawing Based on SDA Instrument*

![Diagram showing Joan's attitude](image)

*Note.* The values for three factors and the emotional satisfaction set of bipolar adjectives from the SDA instrument (Bauer, 2008) are plotted as a percentage of the maximum scale value for the respective factor. The values for anxiety were reversed so that the percentage of maximum scale is consistent with the factors and represents a more positive attitude.
Her positive attitude towards drawing was also evident in her responses during her end-of-semester interview, but unlike the SDA instrument, she contrasted her end-of-semester attitude toward drawing with her prior experiences. She discussed initially having some anxiety regarding drawing, because of unfamiliarity with the science phenomenon.

I think the first time you asking me to draw or explain any kind of phenomenon, there's going to be some kind of anxiety, because I'm not going to know about the phenomenon. But then adding to that drawing, as I added to the washcloth drawing, my anxiety went away and I was fine because I knew I was just drawing my thinking.

Joan discussed the affective characteristic of value most often during her interview, which she attributed to the modeling cycle that allowed her to evaluate and revise her initial ideas. For example, she stated,

When I was in high school, my teachers would ask me to do it and I would hate it because it was kind of boring. But I can see it as being helpful now because we did it so much in our class. I was able to think through my stuff more and think through my thinking more by drawing and because we kept going back to the same drawing, it was really helpful rather than starting a new drawing every time.

Modeling was one of the most mentioned reasons during her interviews when she discussed the value of drawing for science instruction. She expressed that the practice of science modeling was novel to her. For example, when asked what she learned about science teaching, Joan responded, “I guess because we kept going back to the same drawing, which I've never done before, I was able to see how my thinking changed throughout the semester and how my drawing changed and got better throughout the semester.” In addition she discussed the value of drawing to help her express her ideas, stating that “…it just helped me put what I was thinking onto paper.
Something that I couldn't say in words, I could put on paper, if that makes sense.” This sense of value appeared to influence her stated intentions of incorporating drawing in her future practice, because she elaborated on the modeling cycle of create, evaluate and revise, saying “And in teaching, if I did a similar thing with my students, I could see how their drawings changed throughout the semester kind of thing.”

**Physical science.** Of the four PSTs, Joan exhibited the most positive affective characteristics regarding physical science (Figure 4.29), which could be related to her overall content knowledge, as exhibited by her scores relative to the group median on the ATLAST Force and Motion assessment (Figure 4.24) and her responses about physical science during her end-of-semester semi-structured interview. For example, when asked about how prepared she felt to teach science, Joan shared,

> I think I feel more prepared to teach physical sciences because the experiments that you can do with that are sometimes more straightforward. Like forces of motion you could have them pushing cars and that kind of stuff. I guess Earth science is a little bit more stressful in my head thinking just because I don't know as well how to find representations for that. Like the blobs in the bottle experiment, but then I know like I can Google and there's stuff out there that I can find. And same with life sciences. So I guess I feel more prepared for physical science, less prepared for like life ... and the other one. Of the four PSTs, she was the only one who discussed feeling most prepared and comfortable teaching physical science.
Figure 4.29

Joan’s Attitude Towards Physical Science Based on SDA Instrument

Note. The values for three factors and the emotional satisfaction set of bipolar adjectives from the SDA instrument (Bauer, 2008) are plotted as a percentage of the maximum scale value for the respective factor. The values for anxiety were reversed so that the percentage of maximum scale is consistent with the factors and represents a more positive attitude.
Although Joan reported a positive attitude towards physical science in the SDA at the beginning of the semester, by the end of the semester, Joan appeared to have become more positive based on the factors that Bauer (2008) attributed to anxiety and the adjective set attributed to emotional satisfaction. The factor attributed to interest and utility (Bauer, 2008) did not change over the semester, likely due to a ceiling effect. Joan’s self-reported value at beginning-of-semester was 97% of the maximum. Similar to both Avery and Eileen, she reported more a more negative attitude based on the factor of intellectual accessibility, but the decrease was small.

Her responses during the interview indicated that Joan did not view physical science as a difficult subject for her to comprehend. For example, she was the only PST that during her interviews referenced her prior knowledge from her physics course during her sophomore year.

Regarding forces, when we took the balls and rolled them down the ramp, we had talked about that a little bit in that physics class. So that was just kind of reinforcing my knowledge. Because we talked a lot about friction and gravity and there was like a whole unit on forces and how they affect motion. So when we talked about pushing things or rolling things down the ramp, that's when I was reminded of.

In addition, when discussing how prepared she felt for instructing science in the elementary classroom she responded that she realized she did not need to know how to explain all science phenomena and could learn along with her students.

So I think prior to this, just this whole school year, I was a little bit worried about science in all areas, because I was like, I don't know, every single scientific phenomenon that is out there. But then after this year I realized that's okay. And I can learn with my students.
and that kind of stuff. And have them make observations and then work off of their thinking to create future lessons.

Science Teaching. Similar to both Avery and Eileen, Joan reported positive STEB at the start of the science methods course. See Figure 4.30 for her STEB at the beginning and end of the semester based on her T-STEM responses.

Figure 4.30

Joan’s Science Teaching Efficacy Belief (STEB) Based on T-STEM Survey Instrument

Note. The self-reported values for the STEB construct from the T-STEM survey instrument are reported as a percentage of the maximum scale value. The T-STEM survey was administered on two testing occasions: once at the beginning and the second at the end of the semester.
Her more positive STEB was evident in the reflection for her lesson during the first field experience week. She shared in her reflection that

Prior to teaching this probe, I was mostly excited and looking forward to gaining more experience working with students in a classroom. Since beginning school this year, I have found that most of my nerves have calmed since last semester, and I have become much more comfortable working with kids in a professional setting..

Similar to Eileen, Joan also reported more positive STEB by the end-of-the semester (Figure 4.30). In her interview, she discussed how she felt better about teaching elementary science with a more student-centered orientation, commenting “I feel good about it. I think definitely this whole year, I’ve learned more about how science is discussion and observation and having the students do the thinking …rather than me just lecturing, "This is why this happens."

She included examples of how she implemented more student-centered instruction during her lesson with the Page Keeley probe, “Human Body” (Keeley, 2011), such as facilitating student discourse with paired discussions prior to whole class discussion and allowing adequate time for all students to share their ideas with the group.

Possibly due to the focus of the series of lessons on drawing to reason and her second field experience lessons with the “Blobs in a Bottle” (Science Bob, n.d.), her comments about preparation focused primarily on drawing and force and motion during her interview. As mentioned previously for her attitude towards physical science, when discussing how prepared she felt to teach any strand of science, she stated,

I think I feel more prepared to teach physical sciences because the experiments that you can do with that are sometimes more straightforward. Like forces of motion you could have them pushing cars and that kind of stuff. I guess Earth science is a little bit more
stressful in my head thinking just because I don't know as well how to find representations for that. Like the blobs in the bottle experiment, but then I know like I can Google and there's stuff out there that I can find. And same with life sciences. So I guess I feel more prepared for physical science, less prepared for like life. Oh my gosh. And the other one.

Like Eileen, a noteworthy aspect of Joan’s discussion during her interview was her reflection on how she will continue to learn as a teacher along with her students. As mentioned in her attitude towards physical science, when discussing how prepared she felt for instructing science in the elementary classroom she responded “But then after this year I realized that's okay. And I can learn with my students and that kind of stuff. And have them make observations and then work off of their thinking to create future lessons.”

**Joan’s SK Learning Outcomes**

Joan’s SK learning outcomes are organized based on concepts and science drawing. The section on concepts summarizes her ideas about the water-force phenomenon during the series of lessons with explicit instruction. The findings are based on content analysis of her series of drawings, her written explanation, and her responses during the end-of-semester, semi-structured interview. The category matrix for the content analysis of concepts in drawings and written explanation was provided in Table 3.11. The category matrix for content analysis of the interview responses for new force-related conceptual knowledge was provided in Table 3.14. The section on science drawing summarizes how her drawings evolved based on deductive content analysis for aspects of model use, including model relationships, purpose and salient features, and metacognition. Schematics of each of the model aspect categories and associated measures from the drawings were depicted in Figures 3.15 – 3.17. The final category matrix used to code her
drawings for aspects of model use was provided in Tables 3.13. The category matrix for content analysis of the interview responses for new science drawing knowledge was provided in Table 3.14

**Concepts.** As discussed for her attitude towards physical science and the ATLAST force and motion assessment, Joan appeared to have sufficient background knowledge in physical science about force and motion. Her level of knowledge was reflected in her more detailed discussion about her prior physics course as part of her undergraduate studies and how our activities during the semester reinforced what she already knew. When asked about new understandings about force and motion, she shared,

Honestly, not that I can think of, but I also went into this class, like I took the elementary physics class last year, second semester. So then when we did the assessments that we were doing in class, I recognized a lot of the drawings because I had done them the two semesters prior. So the knowledge was still kind of fresh, so I can't think of anything that changed.

She also shared how some of the activities during the science methods course were similar to her prior courses.

Regarding forces, when we took the balls and rolled them down the ramp, we had talked about that a little bit in that physics class. So that was just kind of reinforcing my knowledge. Because we talked a lot about friction and gravity and there was like a whole unit on forces and how they affect motion. So when we talked about pushing things or rolling things down the ramp, that's what I was reminded of.

Her drawing for the Cartesian Diver phenomenon (Figure 4.25) included more non-observable ideas versus observed details to explain what the applied force caused the diver to
sink to the bottom of the bottle compared with the other PSTs. While her ideas were not completely consistent with the canonical explanation, her drawing indicated that she recognized the balance of forces had changed, so that the force of gravity exceeded the buoyant force on the diver. However, her idea centered on the loss of air from under the open stopper used for the diver apparatus, versus recognizing that the air inside the bottle was compressible, and therefore, the air volume in the diver apparatus was reduced and became more dense, which lowered the buoyant force.

Although Joan did not think her understanding of force and motion had changed during the semester, her progression of drawings for the water-force phenomenon (Figures 4.26 & 4.27) and her discussion during her interview indicated that she acquired new knowledge about intermolecular water forces during the series of lessons that included explicit instruction on drawing to reason. The results from the deductive content analysis of Joan’s first drawing, final drawing and written explanation for relevant concepts is provided in Table 4.9. As shown in table, Joan included more concepts related to a canonical explanation of the water-force phenomenon in her final drawing compared with her first drawing, as well as including some of the new concepts in her written explanation. She included 9 out of the 11 coded concepts (see Table 3.11) in her final drawing, compared to 4 out of 11 concepts in her first drawing. In her written explanation, she included five of the coded concepts. She also discussed during her interview that she was not sure she remembered learning about water forces prior to the science methods course.

I think the adhesion and cohesion, I had not heard about that. I don't know if I learned about it in elementary school, but those were new words for me. And so being able to draw that and then refer back to them was definitely helpful.
### Table 4.9

*Concepts Included in Joan’s Drawings and Written Explanation for Water-Force Phenomenon*

<table>
<thead>
<tr>
<th>Big Idea</th>
<th>Concept</th>
<th>First Drawing</th>
<th>Final Drawing</th>
<th>Written Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>All matter in the Universe is made of very small particles</strong></td>
<td>Molecular structure of water</td>
<td>○</td>
<td>●</td>
<td>○</td>
</tr>
<tr>
<td></td>
<td>Molecular charge (water polarity)</td>
<td>○</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td></td>
<td>Particle model for matter</td>
<td>●</td>
<td>●</td>
<td>○</td>
</tr>
<tr>
<td></td>
<td>Spatial structure of liquid vs solid</td>
<td>●</td>
<td>●</td>
<td>○</td>
</tr>
<tr>
<td><strong>Objects can affect other objects at a distance</strong></td>
<td>Gravity</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td></td>
<td>Magnetism analogy</td>
<td>○</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td><strong>Changing the movement of an object requires a net force to be acting on it</strong></td>
<td>Adhesion of water molecules</td>
<td>○</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td></td>
<td>Cohesion of water molecules</td>
<td>○</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td></td>
<td>Compression force on washcloth</td>
<td>●</td>
<td>●</td>
<td>○</td>
</tr>
<tr>
<td></td>
<td>Drag force on water droplets</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td></td>
<td>Unbalanced vs balanced forces</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

*Note: Relevant science concepts to explain the behavior of water being wrung from a washcloth in space versus on earth are based on the Big Idea Tree shown in Figure 3.2.*
While Joan included several of the forces acting on the water molecules on earth and in space (Table 4.9), similar to Avery and Eileen, she did not draw or write about them in terms of their relative magnitude or as a system of forces acting on water. Therefore, the concept of unbalanced versus balanced forces was not coded in the content analysis as new conceptual knowledge in either her drawings or her written explanation. In her interview Joan predominately focused on the polarity of water molecules and the analogy of magnetism. As she discussed her drawings during the interview, she shared,

And then I think I got really into the charges. So then that is what was happening down here. And I was trying to illustrate that and illustrate what we get talked about in class. So I was saying like, maybe a person is more positively charged and water's negatively charged. So then it is attracted to the person in a way. And then that is kind of what I explained more here with the hand.

In addition to the concepts coded in Table 4.9, Joan included more additional ideas on her water-force drawings than the other PSTs. For example, she included representations to communicate her idea of how liquids conform to the shape of their containers to help explain her idea of water filling the spaces of the washcloth on earth. She also hypothesized how different atmospheric compositions on earth versus space might influence the behavior of water on earth due to differences in charge, and she recorded her observations with the water drops on the penny investigation from the fourth lesson.

Compared with Eileen who discussed how she was thinking about her understanding while drawing, Joan appeared to be have used the drawing to either communicate her physical science knowledge or to record her learning. For example, when discussing what she had included in her water-force drawings, she said “So then in my head I was like, ‘This [water
behavior on penny] is really important.’ So then I wanted to reflect that in my drawing somehow. I don't really know how, but I tried to.” While Joan did not focus on the acquisition of vocabulary and labeling, which Avery had discussed in her interview, she did share how the drawing served as a record of what she learned and guided her written explanation.

I guess I used the drawing as a guide to make my explanation. And so if I didn't have this drawing in front of me to make my explanation, I think I would've been a little bit lost. And I think my explanation wouldn't have been as... I don't know how detailed my explanation was, honestly. But I would hope that it was detailed because I had so much drawn on this paper versus I think if we had not drawn, I would've probably lost some of the knowledge that's in this picture. So it would not have been reflected in my explanation as much.

When asked how the drawings were beneficial to her, Joan discussed how the drawings facilitated retrieval of concepts that had been explored during the lessons with the water-force phenomenon.

Also when making my explanation, it was so much easier to look at a drawing than to look at pages and pages of notes. Because if you had asked me to make an explanation, if we had just handwritten notes for the whole semester I would've probably been very overwhelmed and not looked at everything. But the picture put everything in a nice spot altogether that I could look at and recognize immediately, what it meant.

This discussion reflected a more product-oriented view of drawing as an instructional strategy, such as drawing-to-learn, where the drawing serves the purpose of facilitating retrieval of knowledge.
Science drawing. As discussed for Avery and Eileen, Joan’s series of drawings (Figures 4.4 to 4.6) were analyzed for three aspects of model use, including a) model relationships, b) purpose and salient features, and c) metacognition (see Figures 3.15 to 3.17; Table 3.14). The operationalized measures for model relationships were the types of translations included in the drawings (Figure 3.15). For purpose and salient features, the operationalized measures were inclusion of foundational images and scale tools in drawings, frequency of text for explanation versus labeling in drawings, and inclusion of non-observable structures, processes and relationships versus observable features in drawings (Figure 3.16). Metacognition was operationalized based on the frequency of revisions based on type in their drawings (Figure 3.17).

The three aspects of model use were categorized as novice versus more expert based on criteria outlined in Quillin and Thomas (2015) and to reflect Joan’s developing use of drawings as a tool for reasoning. The use of the term novice was not meant to imply a lack of value for other ways that drawing supports learning in science (Ainsworth et al., 2011). As shown in Figure 4.10 and described in Chapter Two, Ainsworth et al. (2011) outlined other valuable purposes of drawing, including drawing-to-learn, drawing-to-communicate, drawing-to-engage, and drawing-to-represent (Figure 4.10). These purposes range from a product-oriented focus on the final drawing to a process-oriented focus on the generation of the drawing. While Joan’s drawing-to-reason may have been novice or more expert based on the model-use aspects, she may have displayed or recognized other important uses for drawing in science during the course, which will be pointed out in the discussion of the coding for aspects of model use from her drawings and from her interviews.
For model relationships, which was operationalized based on the inclusion of different types of translations in her drawings, Joan displayed a more expert use of drawing-to-reason as the series of lessons with explicit instruction progressed (Table 4.10). As she revised her drawings, she included a greater variety of translations, likely reflecting modeled examples included by the instructor during the explicit instruction (Table 3.2).

Table 4.10

Types of Translations in Joan’s Drawings of Science Phenomena

<table>
<thead>
<tr>
<th>Drawing</th>
<th>Visual-Text</th>
<th>Horizontal</th>
<th>Vertical</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Spatial</td>
</tr>
<tr>
<td>Cartesian diver</td>
<td>●</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

*Water-force phenomenon drawing version*

<table>
<thead>
<tr>
<th>Version</th>
<th>Visual-Text</th>
<th>Horizontal</th>
<th>Vertical</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Spatial</td>
</tr>
<tr>
<td>1st</td>
<td>●</td>
<td>○</td>
<td>●</td>
</tr>
<tr>
<td>2nd</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>3rd</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Final</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
</tbody>
</table>

*Note.* In the table inclusion the type of translation is indicated by ●, while no evidence of the translation type is shown by ○.

In her Cartesian diver drawing (Figure 4.25), Joan only included visual-text translation, which was used for representing both observable features and non-observable processes that were part of her explanation. In her series of water-force phenomenon drawings, she included a greater variety of translations as she revised her drawings. She used vertical translations in the first version of the water-force phenomenon drawing (Figure 4.26) to represent water as a particle model and to magnify the washcloth to show her idea of its structure as a solid with water molecules filling spaces on earth versus the washcloth structure without water molecules.
in space. With later drawing versions including the final one (Figure 4.27), she used vertical translations to represent the molecular structure of the water molecules, the bipolar charge of water molecules, and the process of adhesion of water molecules on the hand of the astronaut. Joan also included horizontal translation in her later drawing versions to represent water both as a particle model as well as a stick-and-ball model.

Based on the three operationalized measures for the purpose and salient features aspect of model use, Joan also displayed more expert use of drawing-to-reason after explicit instruction during the series of lessons. Her use of foundational images and scale tools in both the Cartesian diver and water-force phenomenon drawings is shown in Table 4.11. The purpose of the inclusion of textual representations for labels versus explanations in the drawings is shown in Figure 4.31. A graph of her inclusion of non-observable structures, processes, and relationships versus observable features in her series of water-force phenomenon drawings is shown in Figure 4.32. Only the drawing versions of the water-force phenomenon were included in Figure 4.32, because the concepts for the Cartesian diver were different than for the water-force phenomenon, and therefore, were not a useful comparison.

The first operationalized measure for purpose and salient features, was the inclusion of distinct examples of the foundational images and scale tools in drawings. These graphic symbols (Figure 3.4) were introduced and modeled by the instructor as part of the explicit instruction on drawing to reason (Table 3.2). In her drawing for the Cartesian diver (Figure 4.25), Joan used only frames and vectors (Table 4.11). Similar Eileen, Joan used verticals lines in her Cartesian diver drawing to represent a temporal sequence and folded the paper in half to denote location differences for the water-force drawings. As mentioned for Avery and Eileen, Joan’s use of framing likely reflected the instruction, which modeled the use of framing during the lesson.
While vectors were introduced as one of the graphic symbols during the first lesson, Joan’s use of them in her Cartesian may have reflected her prior experience with them from other courses. For example, during her interview, Joan discussed using arrows during her physics course her sophomore year when asked about whether they had drawn during the class.

Yeah, yes we did. It was on Zoom and we were given a workbook that we had to buy.

And we just worked through each section of the workbook, every class and drew our thinking kind of. So we worked a lot with the trains on a track, so like there's no gravity. And so we had to draw arrows to show the direction of force and then that kind of stuff.

So yes, it was a lot of drawing.

Table 4.11

Joan’s Use of Foundational Images and Scale Tools in Drawings

<table>
<thead>
<tr>
<th>Drawing</th>
<th>Frames</th>
<th>Magnification Tool</th>
<th>Particle Model</th>
<th>Vectors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Structure</td>
<td>Process</td>
<td>Force</td>
</tr>
<tr>
<td>Cartesian diver</td>
<td>●</td>
<td>○</td>
<td>○</td>
<td>●</td>
</tr>
<tr>
<td>Water-force phenomenon drawing version</td>
<td>●</td>
<td>●</td>
<td>○</td>
<td>●</td>
</tr>
<tr>
<td>1st</td>
<td>●</td>
<td>●</td>
<td>○</td>
<td>●</td>
</tr>
<tr>
<td>2nd</td>
<td>●</td>
<td>●</td>
<td>○</td>
<td>●</td>
</tr>
<tr>
<td>3rd</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Final</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
</tbody>
</table>

Note. Within the table, inclusion the type of translation is indicated by ●, while no evidence of the translation type is shown by ○.

In her water-force drawings, Joan incorporated more of the other foundational images and scale tools (Table 4.11). She used the magnification tool to represent the structure of water molecules, the solid structure of the washcloth both filled with water on earth or without water in space, the process of adhesion, charge of water molecules or the astronaut’s skin, and the
chemical composition of the air on earth versus space. She also used the particle model to represent water as non-observable molecules with a greater spatial distance between particles compared with the solid washcloth. Based on Joan’s discussion during the interview, inclusion of the magnification tool and the particle model was influenced by the explicit modeling of their use by the instructor after the PSTs generated their Cartesian diver drawings.

The second operationalized measure for purpose and salient features was the purpose of textual representations included in drawings. Joan increased her use of text for both labeling and explanations during the series of lessons on drawing-to-reason (Figure 4.31). In her Cartesian diver drawing (Figure 4.25), the purpose of her text was approximately equal for labels versus explanation. In the water-force drawings, Joan included the most text of the four PSTs. She initially included more text for the purpose of labeling, but by the final drawing, the majority of the text was used for explanations. For example, Joan included textual explanations for the physical properties of water, the compression force on the washcloth from the wringing action, and her hypothesis of an electrostatic charge on the astronaut. Similar to Eileen, her inclusion of text increased as she included more non-observable structures, processes and relationships in her water-force drawings after each lesson, and she represented her ideas with both visual images and text. However, as mentioned with her conceptual learning, Joan appeared to use drawing more as a record of learning or to communicate her ideas, versus as a tool for thinking. During her interview, she did not discuss how the drawing challenged her thinking about the explanation for the water-force phenomenon. When reflecting on the modeling cycle of evaluate and revise, which was part of the explicit instruction interventions, she responded,
And one thing I'm just noticing right now is you kept asking us every week to add something to our drawing. So I just kept trying to draw something every week, even if I didn't know what to draw exactly. But I think that helped my drawing become better.

**Figure 4.31**

*Joan’s Inclusion of Text in Drawings to Explain Science Phenomena*

*Note.* Text phrases were counted as based on their use as a label or as an explanation in the drawings (Table 3.13). Frequency is defined as the total number of occurrences for each category of text in a drawing. The sequential drawing versions for explanation of the water-force phenomenon are referenced as 1st, 2nd, 3rd, and final water phenomenon.
The third operationalized measure for the purpose and salient features aspect of model use was the inclusion of non-observable structures, processes, and relationships versus observable features (Figure 4.32).

**Figure 4.32**

*Joan’s Inclusion of Observable versus Non-observable Features in Drawings*

![Graph showing inclusion of features](image)

*Note.* The drawing version on the x-axis refers to the phenomenon of wringing water from a washcloth in space versus on earth. The frequency on the y-axis refers to the total number of different observable features (Table 3.12) or non-observable structures, processes, and relationships (Table 3.11) coded in each drawing. There was a maximum of 8 distinct observable features and 11 distinct non-observable structures, processes and relationships used. The included representation of the observable features and non-observable structures, processes, and relationships could be either textual or visual in the drawing.
In her first water-force phenomenon, Joan included slightly more observable features versus non-observable structures, processes, and relationships. With subsequent versions of her drawings, she included more visual images to represent both observable and non-observable aspects of her explanation, but the majority of revisions focused on adding more salient features in her subsequent drawing versions. As discussed with both Avery and Eileen, Joan’s third and final drawing versions included the same concepts, which reflects that the last lesson for the water-force phenomenon was a review of the previous lessons’ content.

*Metacognition* was the last aspect of model use that was evaluated by deductively coding for types of revisions or questions (Figure 3.17) in the PSTs’ series of water-force phenomenon drawings. The revisions to drawings were categorized as being based on content from the lesson activities (content revisions) or prompted by instructor feedback on the drawings (prompted revisions). The questions were ideas or information about which PSTs indicated they still wondered in their drawings. The frequency of revisions and questions included in Joan’s series of water-force phenomenon drawings are shown in Figure 4.33.

Of the four PSTs, Joan was the only one who did not initially include an indication of uncertainty about her explanation in her first water-force drawing (Figure 4.26). This may reflect confidence in her level of knowledge about force and motion. However, in subsequent drawings, she did indicate uncertainty about several ideas she included, for example how oxygen on earth might affect the process of adhesion, if there is a difference in the electrostatic charge in space, and if the hand surface has a positive charge to attract water molecules. She also expressed lingering uncertainty in her interview, stating “I know like I drew what I thought about the washcloth, but then I still don't completely understand why the water didn't... I didn't understand completely completely why the water did what it did.”
Figure 4.33

Joan Operationalized Measures of Model Use Based on Metacognition

*Note.* Prompted revisions are changes in PSTs’ drawings due to an instructor prompt. Content revisions are changes based on lesson content. Questions are things that PSTs indicated they still wondered about in their drawings. Frequency on the x-axis is the total number revisions or questions in a drawing. The sequential drawing versions for explanation of the water-force phenomenon are referenced as 1st, 2nd, 3rd, and final on the y-axis.
In addition, Joan had the most revisions of the four PSTs. Her instructor-prompted revisions included clarifying her idea about water “filling the washcloth” and changing the representation of the compression force on the washcloth, which she elaborated on during the interview, saying “And so then I changed my drawing to be a more wringing motion. So being more detailed in drawing.” The remainder of Joan’s drawing revisions were ideas that were added based on the lesson content. In addition to concepts that were included in activities during the series of lessons, she included ideas based on her prior knowledge, such as her hypothesis about difference in electrostatic charges on earth versus space.

While Joan had the most revisions for her drawings, her responses during the interview seems to indicate that she was not necessarily using the drawing for reasoning with her ideas about the water-force phenomenon, but rather to communicate what she thought would be considered the correct answer. She did state that drawings “helped [her] put what [she] was thinking onto paper. Something that [she] couldn't say in words, [she] could put on paper.” However, she also discussed a concern about having to revise drawings if her initial ideas needed to be changed.

If I realized that my thinking was wrong in the past, having to erase it and like redo it, would've been hard. And the only example of that with my drawings was the squeezing. And that I just had to erase an arrow and then redraw it. But if I had done something that I disagreed with on my first drawing and it was really big, it would've been harder to correct in the future.

In addition, her uncertainty about her final drawing appeared to be related to the lack of an instructor-provided explanation about the phenomenon. When asked about how useful she found
drawing for her own learning, Joan responded “So I guess the drawings were helpful, but then they would also be helpful with an explanation in the end, if that makes sense.”

In summary for the drawings during the series of lessons with explicit instruction, Joan overall developed a more expert use of drawing-to-reason based on the three model use aspects. For *model relationships*, she demonstrated more expert use that was evidenced by the increased types of translations she included in her drawings as the lessons progressed. For *purpose and salient features*, she demonstrated more expert use by incorporating more types of foundational images and scale tools, including more non-observable structures, processes, and relationships to explain the water-force phenomenon, and using textual representations for explanations, in addition to labels, as she revised her drawings. However, for *metacognition*, while she did revise her drawings based on instructor-prompts and lesson content, her responses during the end-of-semester interview suggested a more product-oriented use of drawing to communicate ideas or record learning.

*Joan’s PCK Learning Outcomes*

PCK was the final learning outcome of interest for the science methods course with explicit instruction on drawing-to-reason. The PSTs’ lesson plans and their interview discussions of facilitating their lessons were the primary data used to explore how their incorporation of drawing as an instructional strategy would support their students’ use of drawing. As mentioned in Chapter Three for the methodology, the data to explore this learning outcome was more limited due to constraints in the field experiences such as time in a single semester for planning and facilitating their own science lessons and the limited availability of the field mentor teachers for coordination of the science methods course activities due to their classroom responsibilities and schedule. The incorporation of drawing in the lesson plans and interview responses was
deductively coded (Table 3.15) based on whether it would support elementary students’ novice versus more expert model use of drawing-to-reason. The coding was based on the three model aspects, including model relationships, purpose and salient features, and metacognition, which were used to explore how the PSTs used drawing for their own SK learning.

Analysis of Joan’s lesson plans from the first and second field experience weeks are shown in Table 4.12.

Table 4.12

<table>
<thead>
<tr>
<th>Joan’s Incorporation of Drawing in Her Field Experience Lesson Plans</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Field Experience Lesson Plan</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Week One: Page Keeley Probe</td>
</tr>
<tr>
<td>Week Two: Discrepant Event</td>
</tr>
</tbody>
</table>

ø = No drawing; ○ = Novice; ● = More Expert

*Note.* Symbols in tables indicate results from coding for how PSTs’ planned instruction would be anticipated to support elementary students’ use of drawing as the science practice of modeling based on the aspects of model relationships, purpose and salient features, and metacognition (Table 3.15).

As discussed in the subsection about her field experience, Joan used the probe “Human Body” (Keeley, 2011) for her first weeks’ lesson. For the lesson, she did not include drawing as part of her instructional strategies. Joan appeared to have structured her lesson based on her observations of her mentor teacher’s instruction. When asked about the reason for not including
drawing for her lesson during the first field week, she responded that “a lot of stuff that they do in that class is writing based. So we wanted to stay with what they were doing in class.”

In her second field experience week, Joan did include student-generated drawings in her lesson for the “Blobs in a Bottle” (Science Bob, n.d.). Based on her lesson plans and discussion during the interview, she included drawings in ways that could support more expert use based on **model relationships**. For example, she provided instruction and opportunities to express their ideas both as text and as images. In addition, their different drawings were used as a basis for sharing ideas both in small group and whole group discussion, which would allow them to compare various ways to model the phenomenon.

Her incorporation of drawing during her lesson could also support more expert model-use based on **metacognition**. She encouraged them to include their initial ideas to predict what they thought would happen, which they had the opportunity to evaluate and revise after they conducted their investigation. During her lesson for the second field experience week, Joan incorporated some of the visual literacy instruction from the science methods course. For example she included the use of temporal frames for the students’ drawings, explaining “that came from what we were doing in class and I wanted to apply it to the lesson. And the worksheet had a before, during and after section so that they could see the change drawn out.” However, she did not include some of the other visual literacy interventions from the class, such as defining common graphic symbols and modeling their use.

I kind of just let them do it on their own, because they’ve drawn pictures similar to that in class before. But then I also told them to draw arrows to label stuff, that is the only [explicit visual literacy thing that I did].
Joan’s inclusion of drawing during her lesson for her second week of field experience did not appear to support more expert model use based on the purpose and salient features. The purpose of drawing during her lesson focused primarily on students recording what they observed and labeling their images, which is consistent with more product-oriented instructional use for drawing. Prior to the investigation for the 3E lesson, her questions targeted the students’ understanding of science observations. She explained, “…so we went over how to make an observation ... I asked them like, ‘What is an observation?’ [and] ‘How do you make an observation’?” During the students’ investigations with the “Blobs in a Bottle,” her student prompts focused on recording what was happening versus their explanations of why it was happening. When discussing her lesson facilitation, Joan shared,

> When I gave them the worksheets, I asked them to make their drawings as detailed as they could, add color if they wanted to and label everything. And prompting them with that, they did a lot of that, which was nice to see.

Although she had students focusing on observations during the lesson, her reason for including a worksheet with bottles represented was supportive of having students include more salient features of the phenomenon. Regarding the worksheet, she said,

> I guess it's less important for older students, but sometimes students will get stuck on just drawing the bottle and get frustrated, but that was the least important. It was the one thing that stayed the same across all of the experiments. So I wanted to take away drawing that factor and just save time by letting them draw inside.

Based on her interviews, Joan viewed the purpose of student-generated drawings as tools for communication or as a record of learning, which may partly be based on her prior education experiences. When asked how she thought students learned best in science, she responded,
I think making observations and having them come to their own conclusions is really helpful. And then having that backed up, later explained after they come to their own conclusions is really helpful. Because I know in classes, it was helpful to think through it on my own first and then have it explained after.

And while she discussed students’ thinking when discussing the value of drawings in the classroom, her comments focused on it supporting their ability to express ideas.

Yeah, no, I think I have a better appreciation for it than I did before the semester. And understand more why drawing is useful in classrooms, just because it helps students put their thinking on paper. That's my understanding of it.

She also elaborated on ways that drawings were beneficial for students who might struggle to express their ideas with words.

I think it definitely helps students talk through their thinking if they don't know the words for it, just in that kind of way. Because sometimes it's harder to say something and it's easier to draw it out and it creates like a visual that is easier seen than said in words. I think it just helps, especially with younger students just draw out their thinking. Because articulating stuff and writing stuff down is sometimes really hard. And so just being able to draw it and not have to think like, "How am I going to write this in a way that this person's going to understand?" Is really beneficial. And I think it would definitely help me see my students' thinking past just their words. Because sometimes words are hard.

But really wants that final explanation- actually ended up doing a brief explanation for her after the interview to satisfy her interest.

I guess nothing. Okay, with the pictures I think it's really helpful if they're explained after the fact. Because still looking at this, I know like I drew what I thought about the
washcloth, but then I still don't completely understand why the water didn't... I didn't understand completely completely why the water did what it did. So I guess the drawings were helpful, but then they would also be helpful with an explanation in the end, if that makes sense.

Summary of Joan’s Learning Outcomes

This section of Chapter 4 described Joan’s learning outcomes based on affective characteristics, SK, and PCK, which all appeared to have changed during the science methods course that incorporated explicit instruction on drawing-to-reason.

The quantitative and qualitative data strands indicated change in Joan’s affective characteristics towards drawing and teaching during the semester. While the SDA instrument did not indicate a difference in attitude towards drawing at the end of the semester, this may have been due to her highly positive attitude at the beginning of the semester. In interviews, Joan expressed having had positive experiences with drawing during her sophomore-year physics course, although she also shared how engaging with drawing during the methods course had countered some negative perceptions from high school regarding its value. In particular, she discussed recognizing the value of drawing both for her own learning and for science teaching. Her STEB was also more positive at the end of the semester compared to the beginning.

Of the four PSTs, Joan expressed the most positive attitude towards physical science, and the factors associated with anxiety and emotional satisfaction were more positive at the end of the semester. However, similar to the other PSTs, the SDA factor that Bauer (2008) attributed to intellectual accessibility was slightly more negative. The slight decrease in the intellectual accessibility factor contrasted with her interview, in which Joan expressed being most confident
teaching physical science compared with life and earth sciences. Similar to Eileen, she discussed that during her teaching career she could continue to build her knowledge about physical science.

Although the quantitative instrument and her self assessment during her interview did not indicate a change in her SK about force and motion, Joan did appear to learn new knowledge about intermolecular water forces during the semester based on the analysis of her drawings, her written explanation, and her discussion during her interview. She also developed more expert use of drawing-to-reason based on deductive content analysis of her drawings for aspects of model use, including model relationships, purpose and salient features, and metacognition. However, her interview responses suggested that Joan tended to have a more product-oriented view for the purpose of drawing, such as a tool for communication or as a record of learning.

Finally, analysis of Joan’s lesson plans and her interview responses supported PCK learning outcomes regarding drawing as an instructional strategy in science. Joan only included drawing in her science lessons for the second field experience week after explicit instruction on drawing-to-reason during the science methods course. She incorporated drawing in ways that could support elementary students developing more expert model use based on the aspects of model relationships and metacognition.

However, her incorporation of drawing during her lesson reflected more product-oriented purposes, such as drawing-to-communicate and drawing-to-learn, versus drawing-to-reason. For example, she provided graphic organizers with temporal frames for before, during and after the phenomenon and included pre-illustrated images of bottles in each frame. The graphic organizers were meant to help students focus on salient features of the demonstrated phenomenon versus repetitively drawing a bottle, but her talk moves and questions during the lesson focused on what the students were observing versus why the phenomenon was occurring. Similar to the other
PSTs, Joan expressed the intention of incorporating drawing into her future science lessons during her end-of-semester interview, but mainly expressed using it for the purposes of communicating ideas and recording observations.

**Reece**

As a student and future teacher, Reece can be best described as an enthusiastic learner. She was very positive in all aspects of the course, including fieldwork, and made connections across her methods courses to link theory to practice. Serving as her instructor both in her fall engineering methods course and spring science methods course, I had the opportunity to observe her intrinsic motivation to learn and grow as a teacher throughout her junior year in the elementary education program. During in-person class meetings for the science methods course, Reece actively listened and took notes during the instruction-focused portions of the class and was an active contributor to class discussions and activities. She usually was one of the first students to contribute to both small and whole group discussions during class. Similar to the other three PSTs, her shared ideas on assignments and in class discourse indicated reading preparation prior to class meetings.

Her assignments and work for her field experiences made frequent connections to the readings and applied the instructional strategies modeled by the instructor, and she often made interdisciplinary connections across her method courses. Her grades on assessed assignments were always in the 95th percentile for the class. She was very student-centered in her lesson planning and assigned teaching reflections in which she focused on how to best support learning for a range of abilities and background knowledge. For example, she modified her probe for her first field experience week to include fewer choices and a physical model to better support her students’ comprehension of the statements used to assess their prior knowledge. Her focus may
have reflected her interest in students with diverse needs as a candidate in the special education add-on program for elementary education. Her ideas for how students learn best mirrored the content from the science methods course and its structure to have the PSTs engaged with hands-on activities to use to build on knowledge. During her interview, Reece shared,

I think students learn best through hands on experimenting and being able to explore science and then coming up with their own ideas and then having the teacher refine them over time. Doing a series of lessons that are hands on and then adding in the science content knowledge to help refine their thinking.

**Initial Science Epistemological Beliefs**

In the Keeley’s (2010) probe “Doing Science” (Figure 4.2), Reece indicated that she most agreed with Marco’s statement that “I think scientists use different methods depending on their question,” which was the most accurate view of how scientists build knowledge through inquiry. Reece stated that she agreed with Marcos because “scientists use different methods or aspects of the scientific method to make discoveries. I think it depends on the type of research or question the scientist is looking to solve which method they will use” (Reece, Probe Response, Jan. 24, 2022). She disagreed with the other three choices because she recognized their work is systemic but not prescriptive.

I disagree with Antoine because scientists have specific procedures they follow in order to solve a problem or solve a question. Moreover, I disagree with Tamara because not all scientists follow the prescribed steps of the scientific method in order, they may use them out of order or omit steps completely. Lastly, I disagree with Erin because not all scientists use experiments to come to conclusions. They may use other methods of inquiry to come to specific conclusions.
Of the four PSTs, her reasoning reflected the most sophisticated epistemological view of the nature of knowing, since she recognized that experimentation is not the only method for building science knowledge and that scientists use a methodical, but not prescriptive approach to answer questions. Reece did not include ideas that might reflect her epistemological views about the stability and structure of science knowledge (i.e. the nature of science knowledge).

Field Experience Lessons

For her field experience during the semester, Reece was assigned to a third grade elementary classroom. Similar to Avery, she selected the Keeley et al. (2007) probe “Darkness at Night” for her lesson for the first field week. Her mentor teacher did not indicate a preference for the content focus at the beginning the semester to guide Reece with lesson planning, but the selected probe was consistent with third-grade, earth science standards for the North Carolina course of study (NCDPI, 2021a). As mentioned for Avery, the “Darkness at Night” probe elicited students’ ideas about the cause of day and night patterns on earth and the extent of their knowledge about earth’s rotation around its axis.

For the lesson during the second field week experience, Reece used a phenomenon based on the experiment, “Build a Film Canister Rocket,” from the Science Bob website (Science Bob, n.d.), which Avery also used in her second science lesson. The phenomenon involved adding water and an alka-setzer tablet to a film canister that had a press on lid. After the lid was placed on the film canister with the water and alka-setzer tablet, it was inverted on the ground. The gas pressure inside the canister increased as the tablet dissolved, due to generation of carbon dioxide until it exceeded the force sealing the lid to the canister. The unbalanced forces launched the film canister into the air. This phenomenon is similar to the unbalanced forces when launching rockets into space, where the upward force of exhaust produced from the combustion of fuel is greater
than the downward force of gravity. For the lesson with the canister phenomenon and in her reflection, Reece included building knowledge about both the chemical reaction and the unbalanced forces causing the launching of the canister. Her second reflection was a great example of how Reece would make interdisciplinary connections among her methods courses, because she included more explicit ideas to connect social studies, ELA, and mathematics in her proposed series of lessons to build conceptual knowledge about the canister-launching phenomenon compared to other PSTs in the course.

**Force and Motion Knowledge**

Regarding prior knowledge of force and motion, Reece along with Joan appeared to be one of the PSTs with a stronger SK foundation based on correct responses on the ATLAST Force and Motion assessment (Horizons Research Inc., 2011). Her responses were equal or higher than the group median at the beginning and end of the semester, respectively (Figure 4.34).

The difference in the beginning-of-semester and end-of-semester scores likely represents variability between testing occasions, since the retest reliability for the instrument was 0.88 (Horizons Research Inc., 2011). One difference in Reece’s responses, compared with the other three PSTS, was that she scored at least once correct response in all the sub-ideas, including sub-idea E that if an object is moving faster and faster, then there is a net force acting on the object in the same direction as the motion. She also exhibited all three types of knowledge that were assessed by the instrument (see Appendix A), which Horizons Research Inc. (2011) categorized as content knowledge, knowledge use to analyze/diagnose student thinking, and knowledge use for instructional decisions.
**Figure 4.34**

*Reece’s ATLAST Force and Motion Responses Compared to the PSTs’ Group Median*

![Chart showing Reese's correct responses on ATLAST Force & Motion Assessment Relative to Group Median]

*Note.* Reece’s correct responses at the beginning (blue bar) and end of the semester (orange bar) compared with the median for all four PSTs (gray line). Based on the guidelines for use of the ATLAST Force & Motion Teacher Assessment (Horizon Research, Inc, 2011) the specific values are not listed. The bars are plotted with the median line to provide qualitative information for Avery’s general knowledge about force and motion relative to the other PSTs.

**Science Drawings of Force-related Phenomena**

Reece’s drawings from the semester are shown in Figures 4.35 to 4.37, including her drawing to explain the Cartesian diver phenomenon (Figure 4.35), her first drawing for her water-force phenomenon on the second week of the series of lessons with explicit instruction on drawing-to-reason (Figure 4.36), and her final drawing for the water-force phenomenon (Figure
4.37). The description of the drawings here will mainly focus on qualitative description, and a more detailed analysis based on the coding scheme outlined in the methodology will be presented with her SK learning outcomes.

Reece separated her drawing into frames based on a temporal pattern of before, during, and after by dividing the horizontal space into thirds with vertical lines (Figure 4.35). This reflected the visual literacy instruction in the class lesson prior to the Cartesian diver, and the instructor demonstration of how to create temporal frames immediately prior to generating their drawings. Like other PSTs, Reece’s Cartesian diver drawing focused mainly on the observable features; however, she did include some non-observable processes to express her initial ideas about why the diver sank to the bottom of the bottle when squeezed.

In her three different frames, Reece drew and labeled the different observable features of the bottle filled with water, a small air space at the top, the bottle cap, and the floating diver. For the non-observable features, the only other foundational image or scale tool that she used in her Cartesian diver drawing was the vector. In the middle frame in her drawing, Reece included her idea of the water pressure increasing with a straight, upward-directed vector from force applied by hands squeezing the bottle. She used straight vectors directed inward to represent the force from the instructor’s hands. Like Avery, Reece did not draw the shape of the bottle being distorted when the force was applied to it. The sinking of the diver was represented with a straight, downward-directed vector. In the last frame for after force was applied to the bottle, Reece drew an upward-directed vector to represent the diver rose back to the top of the bottle. She did not draw or include text about her ideas regarding what had changed to cause the diver to rise, other than the absence of applied force from hands.
Figure 4.35

Reece’s Cartesian diver Drawing
Figure 4.36

Reece’s First Drawing for Water-force Phenomenon

Wash Cloth on Earth

Wash cloth in Space

- Is there a force acting on the water molecules that hold the water "shells" surrounding the wash cloth?
Figure 4.37

Reece’s Final Drawing for Water-force Phenomenon
In her first drawing of the water-force phenomenon (Figure 4.36), Reece included more non-observable structures, processes, and relationships along with observable features. Consistent with her Cartesian diver drawing (Figure 4.35), she included framing, but used a spatial comparison of earth versus outer space instead of the temporal framing. Like Avery, she divided the horizontal space in half with a vertical line. The orientation of images in her drawing was horizontal with a focus on the washcloth, which occupied most of the framed horizontal area for the earth and for outer space frames. The washcloth was drawn as an oval shape outlined by a wavy line to convey the physical properties of a soft material being wrung out. Vertically the included features occupied approximately the top, two-thirds of the space. Text was included in the drawings to label drawn elements and to provide explanation about the phenomena. She used straight lines to indexically label features in the drawings or provide clarifying explanation for the visuals. Her labels, lines, and shapes were drawn with bold, thick lines, which is similar to Joan’s drawings, but in contrast to the fainter lines in Eileen’s drawing. Although the drawing is legible and clear, it did not have the same level of organization and attention to detail in Avery’s drawings. There is more variability in text size and orientation and a sense of randomness to the represented features, which is more similar to Joan’s drawings.

Her representations of visible water varied and included textual representation and visual representations of a liquid film, oval droplets, and tear-shaped droplets. Differences in the washcloth on earth versus outer space were represented by lighter shading with droplets within the washcloth outline for the water film on earth versus a thicker layer with enclosed water drops around the outside of the washcloth outline. The water layer in space also was drawn with bolder lines in outer space to represent it was more visible. In addition, she drew positive charges on the washcloth in outer space, but not on the washcloth on earth.
Reece also incorporated more of the foundational images and scale tools (Figure 3.4) in her drawings of the water-force phenomenon (Figures 4.36 & 4.37) compared to her Cartesian diver drawing (Figure 4.35). In the drawings, vectors were used for a variety of purposes, including direction, force, and magnitude. Vector shape and direction represented distinct types and direction of force, including a curved arrow for compression force from hands, a downward, straight arrow for gravity, and a straight arrow for forces countering gravity, such as adhesion and air resistance. The straight arrow was upward for the air resistance, but she included small arrows surrounding and pointing towards the washcloth for adhesion. To represent the relative forces on the water droplet, the magnitude of the air resistance vector is shorter than the downward vector for gravity. This was a unique idea included in Reece’s drawings about which she was uncertain since she included a question mark next to the air resistance label. While she used straight lines with textual representations that served the purpose of labels or explanations, she did use an arrow for a text clarification in her final drawing of the water-force phenomenon (Figure 4.37). She explained that the statement “washcloth is still damp” meant that “there was still [a] water layer on wash cloth.”

She used the magnifier scale tool (Figure 3.4) for a variety of purposes in her water-force phenomenon drawings, including vertical translations to compare the spatial organizations of liquids vs solids, to represent the molecular structure of water, and to represent polarity of water molecules. Her representations of the non-observable structures for water included the symbolic representation H₂O, small dots for the particle model from the foundational images (Figure 3.4), and a variety of 2D stick and ball models, including examples with just labeled atoms and others including the distribution of positive versus negative electrical charges. She was also the only
other PST besides Joan to use the magnifying tool to represent the spatial arrangement of molecules for a solid compared to liquid water.

**Reece’s Learning Outcomes Based on Affective Characteristics**

This section synthesizes the quantitative and qualitative data strands exploring Reece’s affective characteristics during the science methods course with explicit instruction on drawing-to-reason. Note that all quotes in the following sections are from Reece’s semi-structured at the end of the semester (Reece, Interview, May 24, 2022). Because affective characteristics are targeted towards something (Anderson and Bourke, 2000), this section is organized by affective characteristics towards drawing, physical science, and science teaching.

**Drawing.** Of the four PSTs, Reece exhibited the largest change in attitude during the semester based on her responses on the SDA instrument (Figure 4.38). In addition to supporting the change in SDA factors and adjective set that to Bauer (2008) attributed to anxiety, intellectual accessibility, and emotional satisfaction, Reece also seemed to express that she felt more self-efficacious about drawing-to-reason by the end of the semester.

The directionality of her initial attitude was mixed based on the different factors described by Bauer (2008). She reported a more negative attitude initially towards drawing based on anxiety and intellectual accessibility, but a more positive attitude based on interest & utility and emotional satisfaction. At the end of the semester, Reece reported the largest positive change in attitude towards drawing based on the factor that Bauer (2008) attributed to anxiety, but she also reported more positive attitudes towards drawing based on the factors attributed to intellectual accessibility and interest & utility, as well as the adjective set attributed to emotional satisfaction. Reece’s responses on the SDA instrument were consistent with her discussion about drawing during her end-of-semester interview.
Reece's Attitude Towards Drawing Based on SDA Instrument

Note. The values for three factors and the emotional satisfaction set of bipolar adjectives from the SDA instrument (Bauer, 2008) are plotted as a percentage of the maximum scale value for the respective factor. The values for anxiety were reversed so that the percentage of maximum scale is consistent with the factors and represents a more positive attitude.
Similar to Joan she discussed her prior experience with drawing during her sophomore physics course, but she did not share the same positive experience. For example, she stated during her interview,

He didn't really explain stuff very well and it was over Zoom too. The only time that we were really drawing was when we were trying to figure out problems, but he didn't actually show us how to draw most of the time because we weren't in a classroom setting. We were on the computer and a lot of our homework too, it would just be multiple choice questions. We didn't need to submit a drawing or submit a written explanation. It was just oh, what's the best answer. I think drawing definitely helps me at least better understand the physics aspect of science.

Her initial more positive attitude based on the interest & utility factor and the emotional satisfaction adjective set reflected her view of herself as “a very visual person,” who “like[s] drawing [and] hands on things.” In addition, her more positive attitude towards drawing at the end of the semester also was consistent by her discussion during her interview, in which she explained,

Yes. I was a little suspicious of drawing at first and science, but now I think it's really, really beneficial and I actually enjoyed it towards the end because I was able to just add to my drawing and it was like a relaxing way to add it. Wasn't as high stakes as writing. I could just add my ideas and not have to go back and do a ton of editing.

These comments about the physics course and drawing were consistent with her initial negative attitude based on anxiety and intellectual accessibility.

Reece most often mentioned the affective characteristic of value during her interview, which is similar to the deductive content analysis of the other PSTs’ interviews. Her perception
of the value of drawing as an instructional strategy in science appeared to have been influenced both by her own learning experiences with drawing-to-reason about the Cartesian diver and water-force phenomenon, and her teaching experiences during the two field experience weeks. Regarding her own learning experiences, she discussed how beneficial she found drawing for expressing her science ideas.

I think it was beneficial because again, I could just draw whatever I was thinking and then go back throughout the semester and edit my drawing and I think that's a lot easier to do as opposed to editing writing, because you can just erase and then redraw or add specific elements, especially if you did a pencil.

In addition to the finding the modelling process of create, evaluate and revise valuable, which is Reece mentioned in the quote above, she also discussed how the visual literacy interventions were valuable for her.

As mentioned in her background information, Reece was pursuing licensure special education as part of her elementary education program. Her interest in how to best support the education of all children in the classroom seemed to be reflected in her discussion of the how she viewed drawing as valuable. During her interview she shared how drawing supported communication of one of the students in her assigned classroom.

I think drawing is really useful as a strategy to facilitate student learning, especially for students who may have trouble with writing out explanations. I know for our first redirect week lesson, we have one student and he's on the autism spectrum and he has trouble writing out complete sentences. He needs help from his aid, but he did, or no, this is our second redirect week lesson, but he did a fantastic job of just drawing the explanation because we did a canned rocket. He was able to draw the forces and the arrows and he
was so excited because he was able to communicate his ideas to the class.

During her field experiences, she noticed the engagement of her students and their ability to communicate their ideas when she incorporated drawing in her science instruction during her field work.

So many of them were more excited about drawing as opposed to writing. I know that for sure, because they're always like, "Oh, do we have to write?" And they were so excited when they were finally able to express their ideas through drawing, which was amazing to see. And then our one student who has trouble writing, actually a lot of our students have IEPs and have difficulty writing and reading and stuff. And I think this was really beneficial for them because they got to express their ideas in another format and they were “Finally. Oh wow, I can actually share with the class. I can present my ideas because I actually have something on my paper,” which was really cool to see.

Reece also shared how student-generated drawings could be valuable for teachers to understand student thinking. When asked if she envisioned incorporating drawing in her own teaching one day, she responded,

Yes, definitely. I think it's an excellent way because I'm actually getting my certain special ed as well. I hope to work in an inclusion setting. I think it's a really great way for students, especially with those who are disability or ELL, especially because they can't necessarily write their thoughts all the time in English to communicate their ideas to the teacher. And you can look at a drawing and be like, "Oh the student understands forces, but they don't necessarily understand a chemical reaction."

When discussing what she had learned about drawing during the semester, she shared,
I learned that drawing is definitely a way for students to express their thoughts in science thinking. And a lot of times people are well, it's not the same as writing. But it allows them to probably provide the same amount of detail. It's just in a different format and a lot of people discredit like, "Oh, it's just drawing. It's not as academically taxing as writing, but at the same time it allows students, especially those with disabilities to communicate their ideas to the class and be able to be a part of the conversation. So I think drawing is very beneficial and I will definitely be including it in my future science teaching.

She supported this view about the value for understanding student thinking by discussing her experiences when teaching the lesson with the can rocket phenomenon.

It helped me better understand what my students were thinking because I was actually able to see their thinking. Our students, they're in third grade so they can write, but sometimes it doesn't make sense. … I think that definitely helped me understand like, oh, this student is lacking knowledge in the fact that the acid tablet reacts with the water, they only put the force. We need to go over what's occurring inside the canister if we were to do another lesson.

**Physical science.** Of the four PSTs, Reece exhibited the most negative affective characteristics towards physical science (Figure 4.39). This was interesting given her level of force and motion content knowledge, as exhibited by her scores relative to the group median on the ATLAST Force and Motion assessment (Horizon Research, Inc, 2011), but it was consistent with comments during her end-of-semester interview.
Figure 4.39

Reece’s Attitude Towards Physical Science Based on SDA Instrument

Note. The values for three factors and the emotional satisfaction set of bipolar adjectives from the SDA instrument (Bauer, 2008) are plotted as a percentage of the maximum scale value for the respective factor. The values for anxiety were reversed so that the percentage of maximum scale is consistent with the factors and represents a more positive attitude.
Reece’s prior educational experiences may have influenced her attitude towards physical science. As mentioned in the prior section regarding her attitude towards drawing, Avery discussed negative learning experiences during her sophomore physics course. Her comment that “I had taken physics a long time ago and just physics is not my favorite. I just never really understood” is consistent with the negative value for intellectual accessibility. She also shared she is more comfortable with “biology and more life science.”

With the exception of the factor attributed to interest & utility (Bauer, 2008), none of the attitude factors changed significantly. However, unlike the other PSTs, the factor attributed to intellectual accessibility was not more negative at the end of the semester. This was reflected as well in her responses during the interview in which she shared that she “definitely [felt] more prepared with physics” and “[was] not afraid to teach physics now,” which she viewed as “that’s good” and attributed to the fact that during the science methods course, “we spent a lot of time going over it.”

**Science Teaching.** Of the four PSTs, Reece expressed the lowest STEB at the beginning of the semester (Figure 4.40). In her reflection for her first field experience lesson on the Paige Keeley probe (2007), “Darkness at Night” Reece shared that she felt “a little nervous” prior to the lesson, but partly due to the fact that she would not be teaching them the correct answer, but rather eliciting student ideas (Reece, First Field Experience Reflection, Feb. 27, 2022).
Note. The self-reported values for the STEB construct from the T-STEM survey instrument are reported as a percentage of the maximum scale value. The T-STEM survey was administered on two testing occasions: once at the beginning and the second at the end of the semester.

In addition, she attributed her feelings of preparation to pedagogical knowledge that she learned during the spring science methods course, which she contrasted with her prior experience in a different methods course from the fall.

I feel more prepared for teaching hands on experiments than last semester. Because we were kind of just like, "Oh, here's a lesson plan that you have to do, make it hands on." Now I understand how to plan a hands-on investigation and think about things that I
really wouldn't have thought about, like procedures in the hallway when you're doing it, safety procedures, because that's not something that I would generally think about. I think that's definitely helpful as well.

Reece also reported that largest positive increase in STEB at the end of the semester compared to the beginning. This large increase in STEB was mirrored in her end-of-semester interview. For example, she discussed her confidence towards physical science in particularly, stating “I think I definitely feel more confident now to teach that to younger students.” In other additional instructional strategies that Reece specifically mentioned as valuable from the science methods course and that she incorporated in her lessons based on how they were demonstrated included eliciting students’ prior knowledge, defining and instructor-modeling of drawing with foundational images and scale tools, and incorporating the model cycle of creating, evaluating and revising with drawings.

**Reece’s SK Learning Outcomes**

Reece’s SK learning outcomes are organized based on concepts and science drawing. The section on concepts summarizes her ideas about the water-force phenomenon during the series of lessons with explicit instruction. The findings are based on content analysis of her series of drawings, her written explanation, and her responses during the end-of-semester, semi-structured interview. The category matrix for the content analysis of concepts in drawings and written explanation was provided in Table 3.11. The category matrix for content analysis of the interview responses for new force-related conceptual knowledge was provided in Table 3.14. The section on science drawing summarizes how her drawings evolved based on deductive content analysis for aspects of model use, including model relationships, purpose and salient features, and metacognition. Schematics of each of the model aspect categories and associated measures from
the drawings were depicted in Figures 3.15 – 3.17. The final category matrix used to code her drawings for aspects of model use was provided in Tables 3.13. The category matrix for content analysis of the interview responses for new science drawing knowledge was provided in Table 3.14.

**Concepts.** Consistent with the other three PSTs, Reece’s progression of drawings for the water-force phenomenon (Figures 4.36 & 4.37) indicated that she had acquired new knowledge about intermolecular water forces during the series of lessons with explicit instruction on drawing-to-reason. The results from the deductive content analysis of Reece’s first drawing, final drawing and written explanation for relevant concepts is provided in Table 4.13. As shown in table, she included more concepts related to a canonical explanation of the water-force phenomenon in her final drawing and her written explanation compared with her first drawing. In her final drawing, she included 10 out of the 11 coded concepts (Table 3.11), compared with only 6 out of 11 in her first drawing. In her written explanation, she included seven of the coded concepts.

Of the four PSTs, Reece was the only one who included the process of balanced forces in her drawing, which she included in her first drawing in relation to the falling water droplet and in her final drawing in relation to the water film on the washcloth on earth. She did not discuss the balance of forces in her written explanation. For the water droplet, she drew a smaller upward-pointing vector to represent air resistance and a larger downward-pointing vector to represent the force of gravity acting on the water droplet. She did not include representation of the force of cohesion between the water molecules in the droplet. During her interview, Reece discussed that “the force of gravity has to be greater because it’s falling downward, and then I guess the force of air resistance would have to be less because it's going down.”
Table 4.13
Concepts in Reece’s Final Drawing versus Written Explanation for Water-Force Phenomenon

<table>
<thead>
<tr>
<th>Big Idea</th>
<th>Concept</th>
<th>First Drawing</th>
<th>Final Drawing</th>
<th>Written Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>All matter in the Universe is made of very small particles</td>
<td>Molecular structure of water</td>
<td>○</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td></td>
<td>Molecular charge (water polarity)</td>
<td>○</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td></td>
<td>Particle model for matter</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td></td>
<td>Spatial structure of liquid vs solid</td>
<td>●</td>
<td>●</td>
<td>○</td>
</tr>
<tr>
<td>Objects can affect other objects at a distance</td>
<td>Gravity</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td></td>
<td>Magnetism analogy</td>
<td>○</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Changing the movement of an object requires a net force to be acting on it</td>
<td>Adhesion of water molecules</td>
<td>○</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td></td>
<td>Cohesion of water molecules</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td></td>
<td>Compression force on washcloth</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td></td>
<td>Drag force on water droplet</td>
<td>●</td>
<td>●</td>
<td>○</td>
</tr>
<tr>
<td></td>
<td>Unbalanced vs balanced forces</td>
<td>●</td>
<td>●</td>
<td>○</td>
</tr>
</tbody>
</table>

Note: Relevant science concepts to explain the behavior of water being wrung from a washcloth in space versus on earth are based on the Big Idea Tree shown in Figure 3.2.
The concept of air resistance was an idea that Reece incorporated based on her prior knowledge, since it was not discussed or investigated during the science methods course. One prior source could have been her fall engineering methods course for which the researcher was also the instructor. Towards the end of the engineering methods course in the fall, the PSTs were designing parachutes and discussed the balance of forces acting on the load of the parachute.

For the process of balanced forces acting on the water film of the washcloth, Reece drew a smaller upward-pointing vector to represent adhesion of the water molecules to the washcloth and a larger downward-pointing vector to represent the force of gravity acting on the water molecules. She did not include a representation for the cohesive force between the water molecules. During her interview about how she drew the water film on the washcloth on earth, she described that “some of it is adhesion to the washcloth, but because I think the force of gravity and the force of the hands was greater. That's why most of the water was able to be wrung out.”

When asked about how she thought her conceptual understanding about force and motion developed or changed over this semester, Reece responded,

I feel like I have a much better understanding of forces in motion over the course of the semester. What really helped me was your drawings on the board. Being able to actually, because again, I'm like very visual and hands on, it … really helped to see the diagrams that you drew. I didn't really have a great idea of how it worked at the beginning of the semester, … but I think having the example of the washcloth, because you don't really think about forces acting on everyday objects. That was really interesting as well. And it helped me better understand that forces act all the time as well.
Reece also discussed some specific aspects of the explanation for the water-force phenomenon that she found beneficial to draw as she worked through her ideas.

Definitely the force of adhesion I think was helpful to understand and draw as well as the water molecules, because previously I wouldn't have even have thought that would've affected how a washcloth acts in space versus on earth. I think that was something that helped.

**Science drawing.** As discussed for the other three PSTs, Reece’s series of drawings (Figures 4.35 to 4.37) were analyzed for three aspects of model use, including a) *model relationships*, b) *purpose and salient features*, and c) *metacognition* (see Figures 3.15 to 3.17; Table 3.14). The operationalized measures for *model relationships* were the types of translations included in the drawings (Figure 3.15). For *purpose and salient features*, the operationalized measures were inclusion of foundational images and scale tools in drawings, frequency of text for explanation versus labeling in drawings, and inclusion of non-observable structures, processes and relationships versus observable features in drawings (Figure 3.16). *Metacognition* was operationalized based on the frequency of revisions based on type in their drawings (Figure 3.17).

The three aspects of model use were categorized as novice versus more expert based on criteria outlined in Quillin and Thomas (2015) and to reflect Reece’s developing use of drawings as a tool for reasoning. The use of the term novice was not meant to imply a lack of value for other ways that drawing supports learning in science (Ainsworth et al., 2011). As shown in Figure 4.10 and described in Chapter Two, Ainsworth et al. (2011) outlined other valuable purposes of drawing, including drawing-to-learn, drawing-to-communicate, drawing-to-engage, and drawing-to-represent (Figure 4.10). These purposes range from a product-oriented focus on
the final drawing to a process-oriented focus on the generation of the drawing. While Reece’s drawing-to-reason may have been novice or more expert based on the model-use aspects, she may have displayed or recognized other important uses for drawing in science during the course, which will be pointed out in the discussion of the coding for aspects of model use from her drawings and from her interviews.

For model relationships, which was operationalized based on the inclusion of different types of translations in her drawings, Reece displayed a more expert use of drawing-to-reason as the series of lessons with explicit instruction progressed (Table 4.14), which was similar to the other three PSTs. As she revised her drawings, she included a greater variety of translations, likely reflecting modeled examples included by the instructor during the explicit instruction (Table 3.2).

In her Cartesian diver drawing (Figure 4.35), Reece only included visual-text translations. In addition for using them for representation of observable features for the phenomenon, she also used visual-text translations for her ideas about non-observable processes, which were similar to Avery. Reece used vectors with explanatory text to represent her idea that the water pressure increased inside the bottle to cause the diver to sink.

In her series of water-force drawings, Reece included a greater variety of translations as she revised her drawings. In addition to visual-text, she used vertical translations in the first drawing version of the water-force phenomenon (Figure 4.36) to represent water as a particle model and to represent the washcloth as more densely spaced particles. With later drawing versions including her final version (Figure 4.37), she used vertical translations to show the structural properties of water molecules, the distribution of positive versus negative electrical charges of water molecules, and the process of a water molecule adhering to the washcloth.
Reece also had examples of horizontal translations, since she used multiple models to represent water at the molecular level, including a stick and ball model, the particle model with dots, and the symbolic representation as H₂O.

Table 4.14

Types of Translations in Reece’s Drawings of Science Phenomena

<table>
<thead>
<tr>
<th>Drawing Version</th>
<th>Visual to Text</th>
<th>Horizontal</th>
<th>Vertical</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Spatial</td>
<td>Structural</td>
</tr>
<tr>
<td>Cartesian diver</td>
<td>●</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Water-force phenomenon drawing version</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>1st</td>
<td>●</td>
<td>○</td>
<td>●</td>
</tr>
<tr>
<td>2nd</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>3rd</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Final</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
</tbody>
</table>

*Note.* In the table inclusion the type of translation is indicated by ●, while no evidence of the translation type is shown by ○.

Based on the *three operationalized measures* for the *purpose and salient features* aspect of model use, Reece also displayed more expert use of drawing-to-reason after explicit instruction during the series of lessons. Her use of *foundational images and scale tools* in both the Cartesian diver and water-force phenomenon drawings is shown in Table 4.15. The *purpose of the inclusion of textual representations* for labels versus explanations in the drawings is shown in Figure 4.41. A graph of her inclusion of *non-observable structures, processes, and relationships versus observable features* in her series of water-force phenomenon drawings is shown in Figure 4.42. Only the drawing versions of the water-force phenomenon were included...
in Figure 4.42, because the concepts for the Cartesian diver were different than for the water-force phenomenon, and therefore, were not a useful comparison.

The first operationalized measure for purpose and salient features, was the inclusion of distinct examples of the foundational images and scale tools in drawings. These graphic symbols (Figure 3.4) were introduced by the instructor prior to the Cartesian diver phenomenon and projected in the classroom while the PSTs generated their drawings to explain the diver phenomenon. While frames to represent a temporal sequence was demonstrated by the instructor prior to the PSTs generating their Cartesian diver drawing, use of other foundational images and scale tools symbols in drawings was not demonstrated explicitly until after the PSTs generated their diver drawing to ensure the ideas that PSTs included in their drawings were not influenced by the instructor.

Table 4.15

Reece’s Use of Foundational Images and Scale Tools in Drawings

<table>
<thead>
<tr>
<th>Drawing</th>
<th>Frames</th>
<th>Magnification Tool</th>
<th>Particle Model</th>
<th>Vectors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Structure</td>
<td>Process</td>
<td>Force</td>
<td>Direction</td>
</tr>
<tr>
<td>Cartesian diver</td>
<td>●</td>
<td>○</td>
<td>○</td>
<td>●</td>
</tr>
<tr>
<td>Water-force phenomenon</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>drawing version</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1st</td>
<td>●</td>
<td>●</td>
<td>○</td>
<td>●</td>
</tr>
<tr>
<td>2nd</td>
<td>●</td>
<td>●</td>
<td>○</td>
<td>●</td>
</tr>
<tr>
<td>3rd</td>
<td>●</td>
<td>●</td>
<td>○</td>
<td>●</td>
</tr>
<tr>
<td>Final</td>
<td>●</td>
<td>●</td>
<td>○</td>
<td>●</td>
</tr>
</tbody>
</table>

Note. Within the table, inclusion the type of translation is indicated by ●, while no evidence of the translation type is shown by ○
Similar to the other three PSTs, Reece used frames and vectors (Table 4.15) in her drawings for both the Cartesian diver (Figure 4.35) and her water-force phenomenon drawings (Figure 4.36 & 4.37). She created temporal frames of before, during and after in the Cartesian diver drawing and spatial frames for earth versus space in her water-force drawings by dividing the horizontal length of the paper with vertical lines. Reece’s used vectors in her Cartesian diver drawing to represent direction of motion and force, including the applied force to the bottle, the force of gravity pulling the diver down, and the represented increase in water pressure. In her water-force phenomenon drawings, she also used vectors to represent the relative magnitude of forces, including gravity versus air resistance on the water droplets and gravity versus adhesion for water molecules on the washcloth on earth.

While Reece’s use of framing likely reflected the explicit instruction on their use, the use of vectors may have been influenced by her prior experience with them from other courses, including her physics class. While Reece did not specifically discuss where she had learned to use vectors as visual representations in her drawing, both Avery and Joan mentioned that they had exposure to drawing force diagrams during their requisite physics course as part of their undergraduate education program.

The other foundational images and scale tools that Reece began to include in her water-force drawings were the magnification tool and particle model. She used the magnification tool when representing the particle structure of both water and the solid washcloth. She also used it to represent the structure of the water molecule as a stick and ball model with a positive and negative distribution of charges. She did represent the process of adhesion for water on the molecular scale, but did not use the magnification tool for the representation. She used the particle model to represent the idea that solids and liquids are composed of molecules and that
the spatial arrangement differs based on the state of matter.

During her interview Reece discussed that visual literacy instruction with the foundational images and scale tools “definitely influenced” her inclusion of them in her drawings. She also discussed how the foundational images and scale tools helped her to feel more self-efficacious about drawing her ideas.

It was definitely challenging because I'm again, not the most artistic person. Just being able to actually draw things a water drop that's a little challenging for me, but the [foundational images and scale tools] made it easier for me to be able to participate. So I appreciate having [them].

The second operationalized measure for purpose and salient features was the purpose of textual representations included in drawings. Reece’s use of text also changed during the series of lessons on drawing-to-reason (Figure 4.41). In her Cartesian diver drawing (Figure 4.35), the majority of the text in the drawing was used for labeling observable features. While she still included text for labeling in her first drawing version for the water-force phenomenon (Figure 4.36), the purpose of the text was divided almost equally between labeling and explanation. In her subsequent revisions of her water-force drawings, she continued to add more text, but it was predominantly for explanations in her drawing.

Her inclusion of text for for explanations increased as she included more non-observable structures, processes and relationships in her water-force drawings (Figure 4.42). For example, after her first drawing version (Figure 4.36), Reece shaded the washcloth on earth to represent a thin water film and added text to explain the washcloth felt damp, which was evidence of the presence of water on the washcloth. Reece, like Eileen, included visual representations, along with explanatory text, for new ideas about non-observables that she incorporated in her water-
force drawings after each lesson, which suggested a more process-oriented use of drawing. In addition, Reece did not discuss her prior science methods’ course focus on drawing and labeling accurately during her interview, which would have suggested a more product-oriented use of drawing.

**Figure 4.41**

*Reece’s Inclusion of Text in Drawings to Explain Science Phenomena*

*Note.* Text phrases were counted as based on their use as a label or as an explanation in the drawings (Table 3.13). Frequency is defined as the total number of occurrences for each category of text in a drawing. The sequential drawing versions for explanation of the water-force phenomenon are referenced as 1st, 2nd, 3rd, and final water phenomenon.
The third operationalized measure for the purpose and salient features aspect of model use was the inclusion of non-observable structures, processes, and relationships versus observable features (Figure 4.42).

**Figure 4.42**

Reece’s Inclusion of Observable versus Non-observable Features in Drawings

![Graph showing inclusion of observable and non-observable features](image)

Note. The drawing version on the x-axis refers to the phenomenon of wringing water from a washcloth in space versus on earth. The frequency on the y-axis refers to the total number of different observable features (Table 3.12) or non-observable structures, processes, and relationships (Table 3.11) coded in each drawing. There was a maximum of 8 distinct observable features and 11 distinct non-observable structures, processes and relationships used. The included representation of the observable features and non-observable structures, processes, and relationships could be either textual or visual in the drawing.
In her first drawing version of her water-force phenomenon explanation, Reece included slightly more observable features compared to non-observable structures, processes, and relationships. However, as she evaluated and revised her drawing, she only added more non-observable structures, processes, and relationships.

After her first drawing, Reece did not include additional non-observable features and focused on including her ideas for why the water behaved differently in space versus on earth. Similar to the other PSTs, Reece’s third and final drawing versions included the same concepts, which likely reflects that the final drawing was revised after reviewing concepts that were explored in prior lessons. Reece explained during her interview that “[she] just took elements of [the] mini lessons, and [she] basically added each of the drawings,” and no additional concepts were investigated during the final lesson.

While the lesson content guided the ideas that Reece included in her drawings, she was more similar to Eileen in using the drawing as a tool for thinking, versus Avery and Joan, who appeared to have a more product-oriented use of drawing during the lessons. During her interview, Reece discussed that “I just think drawing was definitely an easier way to think about my ideas before I wrote them out. Because I could visually see what I was thinking.” In addition, she thought “it definitely helped [her] communicate [her] ideas because with drawing, you can just go back and erase if something doesn't necessarily fit your thinking anymore.”

Metacognition was the last aspect of model use that was evaluated by deductively coding the types of revisions or questions in the PSTs’ series of water-force phenomenon drawings (see Figure 3.13). The revisions to drawings were categorized as being based on content from the lesson activities (content revisions) or prompted by instructor feedback on the drawings (prompted revisions). The questions were ideas or information about which PSTs indicated they
still wondered in their drawings. The frequency of revisions and questions included in Reece’s series of water-force phenomenon drawings are shown in Figure 4.43.

**Figure 4.43**

*Reece Operationalized Measures of Model Use Based on Metacognition*

Note. Prompted revisions are changes in PSTs’ drawings due to an instructor prompt. Content revisions are changes based on lesson content. Questions are things that PSTs indicated they still wondered about in their drawings. Frequency on the x-axis is the total number revisions or questions in a drawing. The sequential drawing versions for explanation of the water-force phenomenon are referenced as 1st, 2nd, 3rd, and final on the y-axis.
As discussed for the other three PSTs, most of Reece’s drawing revisions were made to include concepts relevant to the water-force phenomenon, which had been explored during the lesson. She also included questions about the phenomenon and revisions based on instructor prompts.

Of the four PSTs, Reece included the most questions in her initial drawing for the water-force phenomenon. In her first water-force drawing, she represented the unbalanced forces acting on the water droplet on earth, including the force of gravity and air resistance, but indicated in her drawing that she was uncertain if it was important to consider the drag force by including a question mark. She discussed this uncertainty during her interview.

And I wasn't sure if it was important, but I guess it was a factor I don't know necessarily if it was super important, but it definitely I guess worked on the water because I guess if it's falling, it has to have some air resistance.

Other questions in Reece’s first drawing for the water-force phenomenon included uncertainty about force processes acting on the washcloth or on the water in space.

Because Reece included two separately phrased questions about whether forces were acting on water in space, each was assumed to be a different idea that she wondered about and was coded as separate questions. During the drawing revisions, Reece replaced one of her questions regarding forces acting on water with a visual representation of a water molecule adhering to the washcloth in space. However, she left the second question about force acting on water in her final drawing version, and during her interview, she discussed,

And then for the one on the right, I wasn't sure if there was a force acting on the water to keep it in, but I knew that it wasn't gravity, so that didn't change from my first to my last
one, but I wasn't quite sure about what force was acting on the washcloth to keep the water molecules, I guess around the washcloth in space.

Therefore, her comments suggested that she continued to wonder about the various force processes involved in the phenomenon.

During her second revision, Reece also added an additional question to her drawing, so that there was still a total of four questions remaining in her final version. After exploring the polarity of water molecules during the science methods course in the third week of the series of lessons with explicit instruction on drawing to reason, she included a question about positive charges on the washcloth in space attracting negative charges in the water molecule. She drew positive charges around the perimeter of her represented washcloth and included the stick and ball model with charges on the atoms and wondered if “maybe negative[sic] oxygen molecules [sic] [are] attracted to positive molecules [sic] in the washcloth?”

After her first drawing for the water-force phenomenon, the instructor included several prompts about her initial ideas for why the water behaved differently in space compared to on earth. The prompts included questions about whether Reece thought there was water present on washcloth on earth after it was wrung out and why she had represented droplets within the water film surrounding the washcloth in space. In addition, the instructor prompted her to think more about her questions regarding air resistance and the force processes acting on the water molecules. For the question regarding the washcloth on earth, Reece shaded in the washcloth in her drawing and added text to explain that it was damp. In her interview, she discussed,

For the second one[drawing], I didn't consider if there was a layer of water on the wash cloth. I decided to shade it in a little bit and I answered back, yes. There's water still in the washcloth.
For the other prompts, she provided a text response either on the sticky note with the instructor prompt or on her drawing. Reece discussed the prompts regarding the air resistance and the droplets she had drawn in the water film around the washcloth in space.

And then you wrote, do you think that air resistance is important? And I wasn't sure if it was important, but I guess it was a factor I don't know necessarily if it was super important, but it definitely I guess worked on the water because I guess if it's falling, it has to have some air resistance. And then you asked, are[sic] there droplets or a film? That was just my way of representing water because there weren’t [sic] droplets. There was some little air bubbles, but I don't think that's what those represented when I initially drew it.

Therefore, the use of prompts, which were intended to support Reece’s use of drawing as a tool for reasoning, may have resulted in her viewing the drawing as a tool to communicate answers to instructor-initiated questions.

Based on her drawings and interview responses, Reece was metacognitively aware of what she did and did not understand about the phenomenon and used her drawings to think through her developing ideas, as well as communicate her ideas.

I think drawing and having these ideas beforehand helped me better construct an explanation because I knew I could look at my drawing and then I would write about my drawing as opposed to just being like, "Oh, well this happened, this happened, this happened." And not having my drawing to look at, I don't think it would've been as robust as an answer because I would have to recall things that we did a couple weeks ago. And I forget sometimes what I eat for breakfast. Just having something to look at visually really helped me organize my thoughts in my opinion.
While she discussed how drawing was helpful for constructing her written representation, which was similar to Joan’s product-oriented use of her drawing to communicate ideas or record learning, Reece’s use of drawing appeared to be more process-oriented because she emphasized that it helped her to organize her thinking.

In summary for the drawings during the series of lessons with explicit instruction, Reece overall developed a more expert use of drawing-to-reason based on the three model use aspects. For model relationships, she demonstrated more expert use that was evidenced by the increased types of translations she included in her drawings as the lessons progressed. For purpose and salient features, she demonstrated more expert use by incorporating more types of foundational images and scale tools, including more non-observable structures, processes, and relationships to explain the water-force phenomenon, and using textual representations for explanations, in addition to labels, as she revised her drawings. The measures for metacognition also suggested she predominately used drawing as a tool for reasoning, but she also used it as a tool to communicate answers to the instructor and to record her learning during the lessons on the water-force phenomenon.

Reece’s PCK Learning Outcomes

PCK was the final learning outcome of interest for the science methods course with explicit instruction on drawing-to-reason. The PSTs’ lesson plans and their interview discussions of facilitating their lessons were the primary data used to explore how their incorporation of drawing as an instructional strategy would support their students’ use of drawing. As mentioned in Chapter Three for the methodology, the data to explore this learning outcome was more limited due to constraints in the field experiences such as time in a single semester for planning and facilitating their own science lessons and the limited availability of the field mentor teachers.
for coordination of the science methods course activities due to their classroom responsibilities and schedule. The incorporation of drawing in the lesson plans and interview responses was deductively coded (Table 3.15) based on whether it would support elementary students’ novice versus more expert model use of drawing-to-reason. The coding was based on the three model aspects, including model relationships, purpose and salient features, and metacognition, which were used to explore how the PSTs used drawing for their own SK learning. Analysis of Reece’s lesson plans from the first and second field experience weeks are shown in Table 4.17.

Table 4.16

Reece’s Incorporation of Drawing in Her Field Experience Lesson Plans

<table>
<thead>
<tr>
<th>Field Experience Lesson Plan</th>
<th>Model Use Aspects</th>
<th>Model Relationships</th>
<th>Purpose and Salient Features</th>
<th>Metacognition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week One: Page Keeley Probe</td>
<td>ø</td>
<td>ø</td>
<td>ø</td>
<td>ø</td>
</tr>
<tr>
<td>Week Two: Discrepant Event</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
</tbody>
</table>

ø = No drawing; o = Novice; ● = More Expert

Note. Symbols in tables indicate results from coding for how PSTs’ planned instruction would be anticipated to support elementary students’ use of drawing as the science practice of modeling based on the aspects of model relationships, purpose and salient features, and metacognition (Table 3.15).

As discussed in the subsection on her field experience during the science methods course, Reece used the probe “Darkness at Night” (Keeley et al., 2007) for her first week. Reece was similar to Joan and did not include drawing as part of the activities during her lesson for the first
field experience week. This may have reflected that her planning for the probe was initiated prior to the series of lessons with explicit instruction on drawing-to-reason. She facilitated her lesson in the field after the first week of instruction on drawing-to-reason. While she did not incorporate drawing-to-reason in her lesson, her students were exposed to modeling through the incorporation of an embodied, role-playing game in which they enacted the revolving planets orbiting the sun. During her interview she described how she facilitated student discourse during the lesson.

And then we asked students to reconsider their ideas and we asked if their initial ideas had changed. And then we had students explain their final viewpoints and then not many students changed so we weren't really able to have a discourse where we talked about, "Oh, I disagree because..." But we did add the talk moves to the board in scaffolds that the students could reference them throughout the initial activity. And then at the end we actually didn't reveal the better answer because they were just starting a unit on the solar system. They would find out later. But we explained as long as they had evidence to support their ideas, that's what a good scientific explanation is.

Therefore, she focused on supporting students’ verbal discussion their ideas in ways that mirrored talk moves strategies from the science methods course activities, which had been introduced and modeled by the instructor during the weeks that she was planning her lesson.

The goal for the second lesson was to elicit student thinking about a science phenomenon. Reece selected the phenomenon based on launching rockets made from film canisters (Science Bob, n.d.), which was the same phenomenon that Avery had selected. During the lesson for the second field experience week, Reece did include drawing as an instructional strategy. Her incorporation of drawing reflected many of the explicit instructions on drawing-to-reason from
the methods course, and therefore, would support her students to develop more expert model use of drawing as a tool for reasoning.

Her inclusion of drawing as an instructional strategy in her second lesson would be supportive of more expert use based on *model relationships*, because she was intentional about having the students generate drawings of their explanation for why the rocket launched and then use the drawings during their small group discussions. Therefore, the students had the opportunity to share different ideas for how to model the phenomenon. Unfortunately, Reece shared that they did not have time to allow the students to share their drawings with the whole class; the students only had the opportunity to verbally discuss their ideas.

Regarding more expert use of drawing-to-reason based on the model aspect of *purpose* and *salient features*, Reece supported her students’ inclusion of nonobservable structures, processes, and relationships by demonstrating the use of the foundational images and scale tools on a whiteboard “like how you [the methods instructor] did it in class” prior to students generating their own.

I demonstrated how to draw it. Because we just handed them a blank sheet of paper and then we said, "We're going to show you some scientific … symbols [foundational images and scale tools] that you can draw so that you can really hone in on your science thinking how forces acted on the can rocket." I drew the gravity. I drew one of the magnification just up on the board so that they could visually reference it.

In addition to supporting her students visual literacy for how to represent their science ideas, she also prompted them with questions, such as “What [do you think] was happening inside of the canister?” and “Why do you think it travels that way?”, to encourage them to reason about why the phenomenon happened versus just what they observed.
Finally, Reece’s instruction also supported more expert use of drawing-to-reason based on the model aspect of *metacognition*. In addition to supporting the students’ inclusion of non-observable structures, processes, and relationships, her visual literacy instruction and probing questions encouraged students to evaluate the quality of their drawings based on how they were representing their science ideas. In addition, she provided an opportunity for students to use their drawings in small group discussions to predict other experimental conditions for launching the rocket, such as “the water temperature” or “adding fins to the canister.” This provided the students with the opportunity to evaluate whether their initial drawing could be used for predictions about new experimental conditions or if more detailed ideas needed to be included to help them reason about the phenomenon. And while Reece provided opportunities for students to evaluate their drawings, she shared that time limited their ability to let them revise their drawings.

And then another difficulty was they didn't have enough time because we only had a specific time allotted for the science lesson. If I feel if they would've had more time, their drawings would've been even better. They're good, but I think they could have added more detail.

**Summary of Reece’s Learning Outcomes**

This section of Chapter 4 described Reece’s learning outcomes based on *affective characteristics*, SK, and PCK, which all appeared to have changed during the science methods course that incorporated explicit instruction on drawing-to-reason.

Of the four PSTs she exhibited the largest change in *affective characteristics* towards drawing and teaching at the end of the semester compared to the beginning. Her initial attitude towards drawing at the beginning of the semester was negative and appeared to have been
influenced by her prior coursework. However, her attitude became significantly more positive by the end of the semester, based on the SDA instrument and her interview responses. The affective characteristic toward drawing that Reece discussed most frequently in her interviews was value. She found drawing beneficial and expressed interest in incorporating it into her future science teaching practices because of its ability to support all children in communicating their science ideas. Of the four PSTs, she reported the largest difference in STEB during the semester. Reece also expressed the most negative attitude towards physical science at the beginning of the semester, and it did not change significantly by the end of the semester, based on the SDA. However, unlike the other PSTs, the attitude factor attributed to intellectual accessibility did not decrease at the end of the semester. Reece shared that based on her prior physical science educational experiences that it was “not really her strong suit,” which was consistent with her beginning-of-semester attitude. However, her discussion during her interview did not necessarily address whether her attitude towards physical science had change, but she did express more confidence in teaching it because of the spring science methods course.

While Reece did not express self-efficacy towards physical science, she was one of the PSTs who exhibited the highest level of background knowledge about force and motion based on her ATLAST assessment responses at the beginning and end of the semester. She also acquired SK about intermolecular water forces during the semester based on the analysis of her drawings and written explanation, and she developed more expert use of drawing-to-reason based on the model aspects of model relationships, purpose and salient features, and metacognition. Her interview responses suggested that Reece predominately used drawing during the semester to reason about the water-force phenomenon based on her comments regarding how she expressed her thinking and was able to revise her ideas over time. However, she also had some examples of
more product-oriented views for drawing, such as drawing-to-communicate, which was noted when she responded to instructor prompts on her drawing versions for the water-force phenomenon.

Of the four PSTs, Reece was the one who reflected most on her growth as a teacher during the semester. When asked whether her ideas about science instruction had changed during the semester, she responded,

Yes. They were very different at the beginning versus the end. Initially how I've always experience science teaching was that the teacher would just lecture about a topic and we really didn't get to see many models or hands on. What comes to my mind is just freshman year biology. All my teacher would do was send us Google slides and be like, "Okay, you have to memorize all this information." And it really didn't make sense because it was just all written and there wasn't really any diagrams or hands on experimenting. And I think that over the course of the semester, my ideas have changed because I realized that's not necessarily a wrong way to teach science, but it's probably not the best way because our students really should have visual models and should be able to actually experience the science firsthand instead of just have written out notes or just written out information.

Therefore, her experiences in the science methods course with explicit instruction on drawing-to-reason provided a model and experience with more a more student-centered, constructionist approach to teaching elementary science.

Chapter Summary

This chapter explored the four elementary PSTs’ learning outcomes based on affective characteristics, SK, and PCK during a science methods course that incorporated explicit
instruction on drawing-to-reason about force-related phenomena. Analysis of quantitative and qualitative data strands were synthesized for each PST to provide thick descriptions of their experiences and learning outcomes during the semester. The findings for each PST, which were described in detail in their respective sections and summarized, will provide the basis for an overall understanding of the science methods course with explicit instruction on drawing-to-reason and the PSTs’ experiences in Chapter Five.
CHAPTER 5
DISCUSSION

Case studies as a research method contribute to our knowledge about an entity or phenomena (Yin, 2009). For case studies with embedded subunits, the overall understanding for the case is based on integrating the findings from the individual subunits (Scholz & Tietje, 2002). The purpose of this case study was to contribute to knowledge about instructional interventions during elementary teacher education programs, which may be beneficial for preparing elementary PSTs to teach science. Therefore, this chapter provides an overall, descriptive picture of what was found to be beneficial from an elementary science methods course with explicit instruction on drawing-to-reason based on the findings for the four PSTs presented in Chapter Four.

The central research question for this study focused on PSTs’ learning outcomes regarding affective characteristics, SK, and PCK, which were explored with the following three sub questions:

1. How do PSTs’ self-reported affective characteristics towards drawing, physical science, and science teaching change from the beginning to the end of the science methods course with explicit instruction on drawing-to-reason?

2. How do PSTs’ drawings and ideas about force-related phenomena evolve over a series of lessons that include explicit instruction on drawing-to-reason?

3. In what ways do PSTs incorporate drawing as an instructional strategy in their science lessons for field experiences after explicit instruction on drawing-to-reason?

The findings for Avery, Eileen, Joan, and Reece, the four participating PSTs in the case study, indicated several learning outcomes regarding their affective characteristics, SK of force-related
concepts and drawing as a science practice, and PCK of drawing as a science instructional strategy by the end of the science methods course with explicit instruction on drawing-to-reason.

Learning outcomes based on changes in PSTs’ affective characteristics included more positive attitudes, interest, value, and self-efficacy towards drawing and more positive self-efficacy towards science teaching. However, the PSTs exhibited variable changes in attitudes towards physical science by the end of the course. The PSTs also exhibited increased SK knowledge about force-related concepts such adhesion and cohesion and drawing as a science practice. While the purpose for drawing in their own science instruction varied, all four PSTs demonstrated changes in their PCK by incorporating drawing in their lesson planning and facilitation in ways that reflected the instructional interventions from the science methods course and that provided opportunities for their elementary students to develop more expert modeling use of drawing as a tool for reasoning.

This chapter is organized based on the learning outcomes for the four PSTs. It includes a discussion of the four PSTs who participated in the case study research and a summary of the overall findings for affective characteristics, SK, and PCK. In addition, the chapter includes limitations of the case study, implications of the findings for elementary teacher education, and future directions for the work.

Summary of Participating PSTs

As discussed in each subsection of Chapter Four, the PSTs who participated in this case study had both similar, as well as distinctive characteristics and qualities as learners in the science methods course. All four had similar force-related prior knowledge based on the ATLAST Force & Motion Assessment (Horizons Research Inc., 2011) and were active contributors to the class discussions and activities during the semester. In addition, they were all
reflective on both their strengths and weaknesses for teaching science and focused on growth as future elementary teachers. However, based on their responses to Page Keeley (2010) probe “Doing Science” probe, they had different prior ideas about the source of science knowledge and how it is acquired. In addition, they varied in their initial self-efficacy towards science teaching based on the T-STEM instrument and attitudes towards drawing and physical science based on the SDA instrument. A summary of each PSTs’ characteristics and prior knowledge, which were discussed in more detail in Chapter Four, is provided below.

Avery was an organized and detailed-oriented PST. She expressed initial confidence in teaching science during her field experiences, which was reflected in her self-reported self-efficacy scores on the T-STEM instrument. Her initial ideas about knowing in science revealed a recognition that scientists are methodical, but not prescriptive, in exploring questions, but her answers indicated limited recognition of the numerous ways, such as observations, explorations and modeling, in addition to experimentation that science knowledge is generated. Her prior experiences with drawing as a science practice appeared to have focused mainly on product-oriented purposes such as drawing-to-learn (see Figure 4.10), and she tended to focus on accuracy of observations and labeling with science vocabulary in her own drawings and use of drawing for instruction. While her force-related knowledge was similar to the other three PSTs, physical science was not an area of science in which she felt confident in her knowledge or that she was particularly interested. She shared that she found the life sciences more interesting and exciting as a learner and teacher.

Two attributes that stood out about Eileen during the science methods course were self-awareness and cautiousness as a learner and future teacher. Her initial ideas about knowing in science were based on her prior science educational experiences, which had conveyed the idea
that scientists follow a rigid, linear method to build knowledge. However, her prior experiences in science did support an understanding that science knowledge is generated in multiple ways, and not just by experimentation. Based on her interview responses and her more negative attitude towards drawing at the beginning of the semester, Eileen initially did not like or feel self-efficacious about drawing. However, she did engage with it actively with it during the science methods course, and by the end of the semester, expressed a more positive attitude towards drawing and incorporated in her science instruction in ways that mirrored the course interventions for drawing-to-reason. Like Avery, she felt more confident and interested in life or earth science than physical science and described her understanding of physical science as memorized facts versus a conceptual understanding for the explanations of phenomena.

Of the four PSTs, Joan was the most confident in her knowledge of physical science and shared positive prior experiences in her prior science content-focused courses. She and Reece were the two PSTs in the case study with the higher percentages of correct responses on the ATLAST Force & Motion assessments (Horizons Research Inc., 2011). This confidence with physical sciences was also evident in her self-reported STEB from the T-STEM instrument. During her interview, she shared that she enjoyed leading science activities and discussions with her elementary students in the field. Her prior educational courses also appeared to support an initial more positive attitude and self-efficacy towards drawing. However, her experience drawing prior to the science methods course had been primarily for assessment or communication, which are more product-oriented purposes for drawing (see Figure 4.10). Therefore, both in her own science learning, as well as in her science lessons during her field experiences, she tended to focus on whether drawings depicted correct answers.
Throughout the science methods course, Reece was best described as enthusiastic regarding both her own science content learning and her preparation for teaching science. As mentioned above, she along with Joan had higher percentages of correct responses on the ATLAST Force & Motion assessments (Horizons Research Inc., 2011). However, in contrast to Joan, she did not express confidence in her physical science knowledge, and similar to Avery and Eileen, was more positive about life and earth sciences. Of the four PSTs, she expressed the most sophisticated epistemological view of the nature of knowing, since she recognized that experimentation is not the only method for building science knowledge and that scientists use a methodical, but not prescriptive approach to answer questions. Like Eileen, she initially expressed a negative attitude towards drawing, which was likely related to her prior educational experiences. She also discussed lower confidence teaching science related to prior educational experiences, which was reflected in her lower self-reported STEB at the beginning of the semester. Of the four PSTs, she exhibited the largest change in affective characteristics towards drawing and teaching at the end of the semester compared to the beginning. She and Eileen were the two PSTs who used drawing for their own learning and in their science instruction during their field experiences for more product-oriented purposes that mirrored the instructional interventions for drawing-to-reason, which were incorporated in the science methods course.

While the PSTs varied in their initial affective characteristics, SK and PCK, there was evidence of several learning outcomes regarding their *affective characteristics*, *SK* of force-related concepts and drawing as a science practice, and *PCK* of drawing as a science instructional strategy by the end of the science methods course with explicit instruction on *drawing-to-reason* based on findings from analysis of their data artefacts. The subsequent sections describe what the PSTs learned during the semester.
Learning Outcomes Regarding Affective Characteristics

Sub-question one quantitatively and qualitatively explored learning outcomes based on affective characteristics after explicit instruction on drawing-to-reason. Overall findings for the science methods course included more positive affective characteristics towards drawing and science teaching, but variable differences in affective characteristics towards physical science by the end of the semester. The affective, visual literacy and modeling instructional interventions appeared to all be important for the PSTs’ affective learning outcomes.

PSTs Reported More Positive Affective Characteristics Towards Drawing

The PSTs’ initial attitudes at the beginning of the semester varied towards drawing based on the distinct factors in the SDA instrument (Bauer, 2008). This variability may have reflected differences in their prior experiences with drawing, which they discussed during their interviews. Eileen and Reece had more negative attitudes based on the values for the factors from the SDA instrument. Only the factor attributed to Interest and Utility was greater than 50% of the maximum scale in their responses. In her interview, Eileen discussed not liking drawing prior to the science methods course. She stated that “not only did [she] not really like drawing, but [she] didn't really see the point in why [they] were drawing for school.” In contrast, Avery and Joan indicated more positive attitudes toward drawing at the beginning of the semester. Joan shared positive experiences using drawing during a prior physics content course for her degree.

Regardless of their initial attitudes, the PSTs’ attitudes at the end of the semester were more positive based on the different attitudinal factors from the SDA instrument (Bauer, 2008). Reece had the largest change in attitude based on her SDA instrument responses, and Joan, who had the most positive attitude at the beginning of the semester, reported higher values just for the factor attributed to Interest and Utility. While Eileen’s values for the different attitude factors
were higher at the end of the semester, three of the four factors were still less than 50% of the maximum scale value. Only her attitude factor attributed to Interest and Utility had a value in the upper half of the scale. This is consistent with her responses during the interview in which she shared that “[she] feel[s] better about [drawing]. [She] feel[s] like now, drawing can be more helpful for [her] learning. [But she] still [doesn’t] love drawing.”

In addition to attitude, other positive affective characteristics towards drawing were noted from the PSTs’ interviews. The incorporation of explicit instruction on drawing-to-reason helped the PSTs find value in drawing as a science instructional strategy. Based on the deductive content analysis of the interview responses, the most frequently discussed affective characteristic was the perception of value toward drawings. The PSTs found drawing to be useful for students to express their own thinking and to provide visual support for making meaning in science. For example, Avery discussed her lesson plan for her field experiences and shared that she “wanted to emphasize students referring back to drawings and using those drawings to be able to represent their ideas” and that her students’ drawings “helped [them] to explain how they thought [their] experiment worked.” Reece shared that she thought “drawing is really useful as a strategy to facilitate learning, especially for students who may have trouble with writing out explanations.” This perception of the value of drawing was consistent with the attitude factor attributed to Interest and Utility, which was more positive for all four PSTs at the end of the semester, even for Joan, who had reported a very positive attitude at the beginning of the semester based on her prior experiences.

The instructional interventions also supported PSTs’ more positive self-efficacy towards drawing. The PSTs all noted initial anxiety about not knowing how to draw their science understanding at the beginning of the semester, which was consistent with their reported Anxiety
factor in the SDA survey. However, as Avery mentioned “by the end of the semester, it was okay to understand this drawing isn’t going to be perfect…I want to be able just to try my best and get my ideas down.” This was similar to Eileen who shared that she “learned personally [to] not to stress about making the drawings perfect or look nice.”

The PSTs also expressed interest in incorporating drawing in their future instruction after explicit instruction on drawing-to-reason. All four showed interest in drawing by incorporating it in their lesson plans for the second week of field experiences during the semester. They also discussed plans to incorporate drawing in the classroom during their future teaching careers for a variety of purposes and in all three science strands. Avery, who tended to use and include drawing for product-oriented purposes, shared an interest in used drawing for formative assessment to understand students’ thinking and how ideas for how to incorporate some of the visual literacy strategies during life science lessons. Eileen discussed how it could help her students think more deeply about science phenomena and challenge them metacognitively. Reece, who was seeking additional special education licensure during her education program, was interested in incorporating drawing because of its potential as a learning modality to support all students in the classroom, including those who might struggle with verbal and textual representations of their ideas. Joan also shared an interest similar to Reece for how it could support students’ ability to represent their ideas.

**PSTs Reported More Positive Affective Characteristics Towards Science Teaching**

In addition to supporting more positive affective characteristics towards drawing, the science methods course with explicit instruction on drawing-to-reason supported the PSTs’ development of more positive STEB during the semester. As discussed in Chapter Four, Eileen, Joan, and Reece reported higher STEB on the T-STEM instrument’s science scale (Unfried et al.,
2022) at the end of the semester compared to the beginning of the course. Only Avery’s STEB did not change substantially, but she also shared her initial confidence for teaching science both in her field experience reflections and during her interview. Reece, who had the largest change in affective characteristics regarding drawing, also had the greatest increase in self-reported STEB.

The quantitative measure of an increase in STEB by the end of the semester was consistent with beliefs that the PSTs shared during their interviews. The PSTs associated their STEB with specific instructional strategies they had learned during the semester, which included drawing, but also other examples from the course, such as productive questioning for student-centered discourse and inquiry-based learning. During her interview, Eileen commented that “[she] think[s] [she has] more strategies to teach with, and [she] know[s] more things about the pedagogy side of things.” Reece, who had indicated the greatest change in STEB during the semester, was enthusiastic during her end-of-semester interview about the course activities that she had engaged with during the course, particularly the drawing aspect, and her growth as a teacher.

However, the change in PSTs’ STEB cannot be attributed necessarily to the inclusion of explicit instruction on drawing-to-reason. As outlined for the course context in Chapter Three, the methods course included a variety of content and activities that were consistent with ambitious science teaching (Windschitl et al., 2018) to build the PSTs’ PCK for instructing all three strands of science in grades three to five. PSTs who engaged with the same ambitious science teaching content and activities but did not receive explicit instruction on drawing-to-reason or generated drawings or explanations reported increased STEB based on responses from the T-STEM instrument (Leavens & Davis, 2023). During the science methods course, there were multiple influential factors on the PSTs’ STEB based on the four major sources of efficacy
beliefs from Bandura’s (1997) social cognitive theory, including mastery experiences, vicarious experiences, verbal and social persuasion, and their emotional and physiological states.

Examples of mastery experiences during the semester include PSTs’ learning outcomes regarding drawing as science practice, as well as the opportunity to teach in their field experiences based on PCK and SK they learned by engaging with content and activities from the methods course. In both their reflections for the first field experience week and their end-of-semester interviews, all four PSTs shared successful outcomes of their lessons and their perceived growth as teachers.

The field experiences and methods course also provided vicarious experiences for the PSTs. They had opportunities to observe the enactments of instructional strategies by the instructor during the methods course and by their mentor teachers in the field. However, some of the PSTs had limited vicarious experiences in the field, because of the lack of science instruction in their assigned classrooms.

Verbal and social persuasion occurred during their field experiences in elementary classrooms, since their mentor teachers in the field provided informal feedback on their science lesson plans, as well as their lesson facilitation. Other sources of persuasion included instructor feedback and encouragement on their lesson plans and peer teaching. The PSTs also received peer feedback on both their lesson plans and facilitation of their phenomena-based lesson for their second field-experience week. Lastly, the science methods course focused on the PSTs’ emotional and physiological states through the instructional interventions targeting affective characteristics. PSTs shared positive experiences during the semester in both their lesson reflections and end-of-semester interviews.
The increase in STEB during this study is consistent with prior research studies with elementary PSTs during teacher education programs. Because of the correlation of STEB with the quality and quantity of science instruction in the elementary classroom (Keys & Bryan, 2001), there has been significant interest in the education research field regarding factors that are influential during elementary teacher education program. Only a few will be mentioned here based on their relevance to factors from this study that may have been influential on the PSTs’ STEB.

The results from this study are consistent with McDonald (2021), who found more positive STEB in a group of Australian PSTs in a science methods course, which the participants attributed to the instructor, inclusion of teaching strategies, and opportunities to build conceptual knowledge about science. McDonald (2021) noted that PSTs’ science understanding appeared to be a pre-requisite for confidence in their science teaching, which is consistent with the PSTs from this study, who shared they had more confidence because they realized they could learn alongside their students. The participants in McDonald’s study also associated their more positive STEB with exposure to practical activities to use with their students. This mirrors Reece’s discussion on her increased STEB, which she attributed to having resources from the science methods course to guide her lesson planning and facilitation.

Several studies have reported that the content and activities in science methods classes influence PSTs’ development of more positive STEB (Cantrell et al., 2003). Cantrell et al. (2003) noted statistically higher STEB for elementary PSTs enrolled in advanced methods courses that included science teaching practicums, compared with PSTs in introductory science methods and concurrent content courses. Cantrell et al (2003) attributed the higher STEB to experiences teaching science in the elementary classroom.
While posited as a key factor (Blonder et al., 2014), the role of SK on elementary PSTs’ STEB appears to be equivocal based on the extant research. Some researchers have reported a positive association of PSTs’ SK and STEB (Bleicher & Lindgren, 2005; Palmer, 2006), while others have reported a lack of influence (Avery & Meyer, 2012; Morrell & Caroll, 2003).

Palmer (2006) reported increased STEB for primary PSTs’ STEB during a science methods course, which had the objective of building SK in addition to learning to teach science to elementary students. The study categorized the influence of SK on STEB as a cognitive-content mastery experience. Bleicher and Lindgren (2005) also reported increased STEB at the end of a science methods course for elementary preservice teachers in which constructivist activities were incorporated to build science conceptual understandings. However, it should be noted that in both the cited studies there were multiple factors that may have contributed to the changes in STEB. Because of the holistic nature of the research context in the studies, individual factors of SK or PCK cannot be isolated.

Morrell and Caroll (2003) did not find a significant change in STEB overall for elementary PSTs after content courses in biology, physics, and earth sciences during their sophomore year, although they did report a small, but statistically significant change in PSTs who had lower initial STEB scores. Avery and Meyer (2012) also reported mixed results for elementary PSTs after an environmental biology content course that had been designed to provide inquiry-based learning. Overall, they saw an insignificant change in the PSTs’ STEB between the pre- and post-course testing occasions. When they subdivided the PSTs based on groups for increased STEB or decreased STEB, the PSTs who improved had significantly higher STEB post-course. However, the correlation of academic performance and knowledge gains with the higher STEB is not clear from the study.
PSTs Varied in Their Reported Affective Characteristics Towards Physical Science

Compared with drawing, PSTs’ attitudes towards physical science varied at both the beginning and the end of the semester based on the different attitudinal factors from the SDA instrument (Bauer, 2008). This variability may have reflected differences in prior educational experiences in the physical sciences and confidence about their knowledge. Avery, Eileen, Joan, and Reece had slightly different scores on the ATLAST assessment indicating some differences in force-related knowledge, and during their interviews, they shared different prior educational experiences and interests in physical science. Palmer (2002) and Tosun (2000) have discussed how science educational experience influence PSTs’ attitudes towards science regardless of academic achievement.

Avery, Eileen, and Joan indicated neutral to positive attitudes towards physical science based on their SDA responses, while Reece’s responses indicated a negative attitude at the beginning of the semester. Joan, who along with Reece, seemed to have stronger prior force and motion knowledge and discussed feeling prepared to teach physical science content in her interview, had the most positive attitude based on the values for each of the different attitudinal factors. During her interview Joan shared positive educational experiences in her physical science courses. Her positive experiences contrast with Reece, who discussed negative educational experiences in the physical sciences. She shared that “[she] had taken physics a long time ago and just physics [was] not [her] favorite. [She] just never really understood.”

In addition to different attitudes at the beginning of the semester, the PSTs varied in their changes in attitude during the semester. Avery’s attitude towards physical science became more negative during the semester based on her responses in the SDA instrument, which may be related to her expressed concern about physical science SK, particularly for the upper elementary
grades. In addition, she indicated that she liked the life sciences better than physical science. However, Eileen and Reece, who also shared more interest in life science than physical science, had relatively stable attitudes overall towards physical science based on their SDA responses at the end of the semester compared to the beginning. Reece did appear to indicate a change in the attitudinal factor attributed to Interest and Utility, while for Eileen, the only attitudinal factor that appeared to be different between testing occasions was Intellectual Accessibility.

The Intellectual Accessibility factor was more negative for three of the four PSTs, including Avery and Joan in addition to Eileen. This perception of physical science as difficult is consistent with elementary PSTs’ reported attitudes towards physical science in the literature. For example, PSTs from UK and Finland reported negative attitudes towards teaching physics based on perceived difficulty regarding the topic, which was assessed by an SDA instrument (Johnston & Ahtee, 2006).

In this study, the more negative perception of the difficulty of physical science may have been related to several factors from this course. One may be related to changes in PSTs’ metacognitive awareness of the breadth of physical science content due to the lessons on the intermolecular water forces. The PSTs all commented that this was new force-related conceptual knowledge during their interviews. The lessons and drawings may have encouraged them to reflect on their current knowledge and a need to build more robust understanding regarding physical sciences. For example, Avery discussed in her interview how she became aware of deficiencies in her knowledge base during the semester.

An additional factor influencing the negative perception of difficulty towards physical science may have been the timing for administration of the SDA survey instrument relative to the ATLAST force & motion assessment at the end of the semester. The beginning of the semester
SDA instrument was completed prior to the ATLAST force & motion assessment, but the end of the semester SDA survey was administered after the second testing occasion for the ATLAST. This may have raised their awareness of the limitations of their physical science knowledge regarding force and motion.

The intended purpose of the ATLAST instrument is not academic assessment of individual teachers, but rather effects of instructional interventions on the collective knowledge of a group of teachers (Horizons Research Inc., 2011). Therefore, the instructor did not provide formal feedback or scores to the PSTs about their responses on the ATLAST assessment after either testing occasion. Test-taking has been shown to be a type of learning monitoring (Weinstein & Underwood, 2014), and feedback can be important for metacognition about performance (Callender et al., 2016). Along with the timing of the ATLAST assessment relative to the SDA instrument, the lack of feedback on correct responses may have contributed to uncertainty about their physical science knowledge and their perceptions of intellectual inaccessibility.

While drawing in general has been posited to influence affective characteristics, the arguments are predominately anecdotal and not empirically based (van Meter & Garner, 2005). For science, there is limited research regarding the influence of drawing on attitudes towards science to compare with outcomes from this study. The available empirical evidence appears to be from several thesis and dissertations. Rosink (2012) found no difference in eighth grade, German students’ attitudes towards science after a unit of lessons on the solar system, which incorporated student-generated drawings with the software tool called SimSketch (van Joolingen et al., 2010). A similar study by Schmalz (2012) with fifth grade German students reported more positive attitudes for the male students only. A limitation for both these studies is the use of a
unidimensional construct termed attitudes towards science, which they constructed from a series of questions based on instruments reporting multiple attitudinal factors (Francis & Greer, 1999; Kind et al., 2007). In her dissertation investigating observational drawing in biology, Landin (2011) did not find significant changes in her operationalized measure for attitude, which she attributed to flaws in her experimental design since the participants were undergraduate biology majors, who reported positive attitudes at the beginning of the course.

**Instructional Interventions Influenced Affective Characteristics**

Quillin and Thomas (2015) proposed that explicit instruction for drawing-to-reason should begin with interventions targeting affect. This initial step in the instructional framework was important for encouraging the PSTs to engage with drawing-to-reason regardless of their initial attitudes, interests, value, and self-efficacy towards drawing. In addition, their instructional framework included influential roles for visual literacy and modeling interventions on affective characteristics. According to Quillin and Thomas (2015), in addition to the direct effect of explicit instruction targeting affect, as students become more expert users of drawing due to visual literacy and modeling interventions, learning outcomes from those interventions will be influential on affective characteristics. The descriptive findings from this study support this aspect of their framework. All three instructional interventions appeared to have played a role in the observed changes in the PSTs’ affective characteristics during the semester based on the quantitative measures from surveys and corroborating responses from interviews.

In their end-of-semester interviews, PST comments about the value of drawing and their self-efficacy were associated with the specific instructional interventions incorporated in the course. Avery, Eileen, Joan, and Reece found the affective interventions and feedback from the instructor encouraging and reported modeling it in their own fieldwork experiences. They also
discussed the usefulness of the foundational images and scale tools for their own learning and for their instruction during their field experiences. In addition, all four PSTs found the re-iterative nature of the modeling instruction valuable for their own learning. They had no prior experience with the modelling steps of create, use, modify, and revise and liked how it gave them the opportunity to visually see how their thinking changed and how they were building their own conceptual knowledge, which they noted would not be as readily apparent in a written explanation. For example, Joan commented that “[she] was able to …think through [her] thinking more by drawing…because [they] kept going back to the same drawing.” They also found the modeling interventions useful in their field experience lessons. Reece and Eileen both mentioned the value of modeling during their interviews and made opportunities for their students during their field experiences to revise their own drawings. Eileen expressed how allotted time for her lesson had limited her students’ opportunity to evaluate and revise their drawings.

**Significance of Learning Outcomes Regarding Affective Characteristics**

Findings from this study add to a limited body of knowledge on affective learning outcomes from engaging with drawing (Van Meter & Garner, 2005). In particular, the PSTs’ learning outcomes regarding affective characteristics are salient because of their potential connection to and possible influence on their SK and PCK. Kind, Park, and Chan (2022) noted the need to better understand the affective aspects of teacher education programs in conjunction with their knowledge of science concepts and PCK and recommended research should include all three aspects when investigating how they influence high quality science instruction. The overall findings for the learning outcomes regarding affective characteristics, including more positive attitudes, interest, value, and self-efficacy towards drawing and more positive self-reported
STEB supports explicit instruction on drawing-to-reason as a beneficial practice to include in elementary teacher education programs. In addition, the positive affective learning outcomes support Quillen and Thomas’s (2015) conceptual framework for instruction on drawing-to-reason as applicable for other domain areas, in addition to undergraduate biology. The affective, visual literacy and modeling instructional interventions appeared to all be important for the PSTs’ affective learning outcomes.

**SK Learning Outcomes**

SK learning outcomes were another area of interest for this study, because of its role in supporting quality science instruction that is aligned with reform-oriented practices in the classroom (Brobst et al., 2017) and student achievement (Diamond et al., 2014). Sub-question Two quantitatively and qualitatively explored *SK learning outcomes* about force-related phenomena and the science practice of drawing after *explicit instruction* on *drawing-to-reason*. PSTs’ conceptual knowledge about intermolecular water forces, which was the focus of the series of lessons on *drawing-to-reason*, were assessed based ideas included in the PST-generated drawings about the force-related phenomena and their final written explanations. Their knowledge about drawing as a science practice was assessed based on aspects of model use in science, including model relationships, purpose and salient features, and metacognition (Quillen & Thomas, 2015). Overall findings from the data analysis indicated that the lessons with explicit instruction on drawing-to-reason supported the PSTs’ acquisition of new conceptual knowledge about intermolecular water forces and knowledge about the practice of drawing, although the purposes for which the PSTs used their drawings during the lessons appeared to vary.
PSTs Learned New Force-Related Concepts

Based on their series of drawings, written explanations, and interview responses, all four PSTs learned new force-related concepts, as well as new ideas about the physical properties of water molecules. However, they did not seem to translate the intermolecular water force concepts that were the focus of the lessons with instruction on drawing-to-reason to the more macroscopically scaled force and motion ideas on the ATLAST instrument. While their SK learning cannot be attributed solely to generating drawn explanations, PSTs did discuss how the drawings supported their learning during interviews.

One measure of the PSTs’ force-related knowledge during the science methods course was the ATLAST force & motion assessment (Horizons Research Inc, 2011), which was administered on two separate testing occasions, including the beginning of the course and after the lessons with explicit instruction on drawing-to-reason. The ATLAST instrument assessed force & motion knowledge based on ability (a) to recall ideas, (b) to understand student thinking, and (c) to make instructional decisions based on student ideas. A range of force and motion ideas were included in the instrument (see Table 3.7), but none specifically covered the concepts related to intermolecular water forces. Based on the median scores from both testing occasions, their general force and motion knowledge did not change during the semester. The results from the ATLAST instrument corresponded to the PSTs’ responses during their interviews in which they shared that they did not think their knowledge of force and motion had changed during the semester.

However, all four PSTs discussed that the intermolecular water forces from the series of lessons was new information for them. The PSTs’ discussion of new knowledge in their interviews was consistent with the visual content analysis of their generated drawings about the
water behavior being wrung from a washcloth in space versus on earth. All four PSTs’ drawings indicated an evolving understanding of the force-related concepts that explained the phenomenon. As discussed in Chapter Four, Avery, Eileen, Joan, and Reece included more ideas aligned with canonical concepts for the phenomenon explanation in their final drawings compared to their initial drawings. However, they tended to focus on adhesion as an individual force that was responsible for the water sticking to the washcloth in space, versus the relative balance of forces, including cohesion, adhesion, and gravity, governing the water motion. Of the four PSTs, Reece was the only one who seemed to consider the balance of forces in her drawings. However, she did not include it for the water on the washcloth, but rather the force of gravity versus air resistance affecting the descent of water droplets on earth. The series of lessons had included several hands-on activities, including the investigations of water droplets on a penny and water droplet shapes on a variety of material surfaces, to support meaning making about the balance of forces, but not clear if it supported the PSTs’ developing conceptual ideas to explain the water behavior in space versus on earth. They all shared the idea that there is no gravitational force in space instead of recognizing that gravity is everywhere, but the relative magnitude varies.

The ideas that PSTs expressed in their written explanations reflected the ideas included in their drawings, however, they did not include as many concepts in their written explanations. All their drawings included concepts categorized by the big ideas (Harlen, 2010) that supported an explanation of the water-force phenomenon, including (a) the particle composition of all matter in the universe, (b) objects affect other objects at a distance, and (c) change in an object’s movement requires an applied net force. However, their written explanations focused mainly on gravity acting from a distance and the forces of adhesion and cohesion. This likely reflects
comments during their interviews of aspects of the explanation, such as molecular structure and charge, which were easier to draw versus the forces that they found easier to represent with text.

As discussed for the PSTs’ STEB, due to the design of the study, the learning outcomes regarding force-related concepts cannot be attributed solely to the drawing instruction interventions or the process of drawing. There were multiple hands-on activities and demonstrations that were intended to help the PSTs construct explanations for the water-force phenomena. For example, Eileen discussed that “the activities made [her] see [adhesion and cohesion] in different ways. [She] really liked the penny activity, with the water droplets. [She] felt like that helped show what adhesion and cohesion are.” However, the PSTs also discussed how they valued drawing during the course for their own learning. Eileen commented that “[she thought] drawing pushed [her] thinking deeper.” During her interview, Joan discussed the role that drawing played in helping recall the concepts of adhesion and cohesion when writing her explanation, sharing that “being able to draw that and then refer back to them was definitely helpful.”

There is evidence outside the field of elementary teacher education for the role of drawing-to-reason in building conceptual knowledge about science phenomena. Cooper et al. (2017) summarized research findings from two different chemistry curriculums, Chemistry, Life, the Universe, and Everything (CLUE) and The Connected Chemistry Curriculum (CCC), which include drawing as a form of model-based reasoning. They have been used to support learning during chemistry courses with undergraduate students in STEM-related majors to support development of core ideas about chemistry, which are defined as ideas central to understanding chemical phenomena such as different physical and chemical properties of diamonds versus graphite, which are both composed of carbon but behave differently. Undergraduate students
who engaged with CLUE had better understandings of intermolecular forces, and students from the CCC had greater learning gains on concepts of matter, solutions, and equilibrium than students from the control group who did not draw-to-reason during their chemistry courses.

**PSTs Gained Knowledge about Science Drawing**

In addition to supporting new conceptual knowledge, explicit instruction on drawing-to-reason about force-related phenomena helped PSTs develop SK about the use of drawing as a science practice to build knowledge. Evidence of PSTs’ drawing knowledge was based on the content analysis of the PSTs’ series of explanatory drawings about force-related phenomena. Since the instructional interventions in the science methods course targeted drawing-to-reason, which is categorized as a type of modeling, the PSTs’ drawings were analyzed based on model use aspects, including model relationships, purpose and salient features, and metacognition (Quillin & Thomas, 2015). The model aspects used for operationalized measures for PSTs’ knowledge are consistent with components of metamodeling knowledge that Schwartz et al. (2009) used as they developed a learning progression for incorporating modeling in the science classroom for elementary and secondary students and with Upmeier zu Belzen’s (2019) model competency framework.

After instruction on drawing-to-reason, PSTs incorporated a greater variety of representational translations in their drawn explanations, which was the operationalized measure for model relationships. In addition, PSTs increased use of foundational images and scale tools; used textual representations for explanations versus labeling; and included more non-observable structures, processes, and relationships as they evaluated and revised their drawn explanations, which were the three operationalized measures for model purpose and salient features. Finally, PSTs independently evaluated and revised their drawings based on new conceptual ideas from
lesson activities and included indications of remaining questions about the water-force
phenomenon, which were the operationalized measures for metacognition. Although changes in
drawing knowledge were noted for all four PST participants, the purposes for which the PSTs
used their drawings during the series of lessons seemed to vary.

**Explicit Instruction Supported PSTs’ Use of Drawings Based on Model Relationships.** Model relationships refers to the representational correspondence between a
model and reality or among multiple models. Novice versus expert model users will differ in
how they view the relationships between a model and its represented phenomenon, as well as
among models of the same phenomenon. More expert model users recognize that there is not
one-to-one correspondence between a model and reality, and that there are multiple ways to
model the same phenomenon depending on the purpose. They can translate ideas easily between
textual and visual representations, as well as “translate among models on the same
[representational] scale, and between models on different [representational] scales” (Quillin and
Thomas, 2015, p.8). In drawings, expert model users represent ideas with both images and text
(visual-text translations), with different visuals on the same spatial scale (horizontal translations),
and with visuals on different spatial scales (vertical translations).

For this research, the types of translations that PSTs incorporated in their drawings were
used as the operationalized measure for model relationships. During the lessons with explicit
instruction on drawing-to-reason, the PSTs incorporated a greater variety of translation types as
they evaluated and revised their drawn explanations for the water-force phenomena. The PSTs
used visual-text translations in all their drawings throughout the series of lessons, including in
their initial drawings about the Cartesian diver, but initially they did not include horizontal or
vertical translations. However, as the lessons progressed, more translation types were
incorporated for multiple purposes, including depiction of spatial and structural information, physical properties, and force processes.

The visual literacy and modeling interventions from the explicit instruction appeared to support the PSTs’ knowledge of model relationships. Visual literacy instruction during the science methods course included guided demonstration of the use of graphic symbols, such as the magnification tool, which the PSTs used in revised drawings to depict information about liquid water on different representational scales (e.g., water as a visible liquid versus its molecular structure structure). The PSTs also included horizontal translations in their revised drawings by depicting multiple representational forms of water molecules in their drawings. The different forms included in the drawing reflected various models of water molecules that were demonstrated or explored during the lessons. Evaluation and revision of drawings as part of modeling intervention provided opportunities for the PSTs to incorporate the different translational types as they were building knowledge about the water-force phenomenon. In the semi-structured interviews, the PSTs also discussed how the drawings helped them express their explanations for the water-force phenomenon as written text. For example, Avery shared that “[the drawing] helped as a guide for what to include in the [written] explanation.”

**Explicit Instruction Supported PSTs’ Use of Drawings Based on Purpose and Salient Features.** This aspect of model use addressed whether PSTs included non-observable structures, processes, and relationships in their drawings to explain the water-force phenomena and used their drawings for more process-oriented purposes, such as drawing-to-reason, as opposed to more product-oriented purposes such as drawing-to-learn (Ainsworth et al., 2011). This aspect of model use was operationalized based on (a) PSTs’ inclusion of foundational images and scale tools in drawings, (b) PSTs’ purpose for inclusion of textual representations in
drawings, and (c) frequency of observable features versus non-observable structures, processes, and relationships included in drawings.

Based on the operationalized measures, PSTs included more salient features with each reiteration of their drawing about force-related phenomenon. As PSTs evaluated and revised drawings during the lessons, they included more foundational images and scale tools as part of their explanations. With the Cartesian Diver, the PSTs only incorporated frames, which were used to depict temporal changes, and vectors, which were used to show force or direction. With the series of drawings on the water-force phenomenon, PSTs also incorporated the magnification tool to depict non-observable details and the particulate model to help compare liquids and solid structure. In addition, text that was included in the drawings progressed from primarily a focus on labeling features to an explanatory role that complemented visual representations in their drawings. Lastly, their first drawing of the Cartesian diver focused on observable, macroscopic features for the phenomenon. However, with each subsequent lesson focusing on intermolecular water forces, PSTs included more non-observable details that explained the phenomenon, such as the particle composition of liquid water, molecular structure of water, polarity of water, adhesion, and cohesion.

The inclusion of more salient features about the water-force phenomenon in this study contrasts with the findings from the Harrell et al. (2022) study with PSTs who drew about buoyancy. In their PSTs’ drawings, Harrell and colleagues noted a lack of visual representation for concepts that reflected a deeper understanding of buoyancy, for example relative density of matter, fluid properties, Archimedes principle, and balanced versus unbalanced load. However, their study did not provide visual literacy or modeling interventions for the PSTs’ use of drawing. In addition, their prompt for the PSTs to “draw and label a picture that shows the forces
acting on the boat,” may have influenced what the PSTs included in their drawings. In the current study, PSTs were prompted to draw an explanation for why they thought the water behaved differently when wrung from a washcloth in space versus on earth. The prompt used in this study was meant to convey that all PSTs’ ideas were valuable and that there was not one correct answer that should be provided.

In addition, the visual literacy intervention in this study supported PSTs’ inclusion of more salient features in their drawings. The initial lesson for the water-force phenomena included an overview of the foundational images and scale tools, which could be used to depict non-observable structures, processes, and relationships. Prior to drawing their explanations for the Cartesian diver, the instructor only explicitly modeled how to create temporal frames by subdividing the paper, which all four PSTs used for their own drawings. Vectors were the only other graphic symbol that the PSTs included in their Cartesian diver explanations, likely due to familiarity from prior educational experiences. Both Avery and Joan discussed familiarity with vector use from the prior physics course. After the instructor explicitly modeled incorporation the different foundational images and scale tools in a drawn explanation for the Cartesian diver, the PSTs began to incorporate them in their own drawings. The PSTs discussed the value of the instructor’s drawing demonstrations during their interviews. For example, Eileen shared that “[she] was also never really taught to do [drawing] like [they] were this semester.”

The influence of the instructor’s explicit modeling for how to use the graphic symbols in drawing-to-reason reflects Lunenberg et al. (2007) discussion on the importance of teacher educators’ practices on PSTs’ learning outcomes. They advocate that what the teacher educators actively do in their classrooms with PSTs is more important than the content they verbally convey for shaping the PSTs’ beliefs and knowledge for their own practices. According to
Korthagen and colleagues, “How I teach IS the message” (Russell, 1997, as cited in Lunenberg, et al., 2007, p 588). In this study, telling the PSTs about graphic symbols was not adequate to influence incorporation in the explanatory drawings for the water-force phenomena; they needed to see the practice modeled by the instructor.

However, while the explicit instruction targeted drawing-to-reason, Avery, Eileen, Joan, and Reece appeared to use drawing for various purposes during the science methods course based on the PSTs’ interview responses and the three operationalized measures, particularly the purpose of text inclusion. As discussed in Chapter Two, there are a range of instructional purposes for drawing in science. In addition to drawing-to-reason, which was the focus of this research, Ainsworth et al. (2011) outlined other purposes of drawing, including drawing-to-learn, drawing-to-communicate, drawing-to-engage, and drawing-to-represent (Figure 4.10). These purposes can be categorized along a spectrum of being product-oriented to process-oriented. For product-oriented purposes, the goal is a final drawing that serves as a record of learning, for example, the use of drawings as an assessment of learning or as documentation to reinforce and recall new vocabulary. For process-oriented purposes, the goal is learning through the generation of a drawing, for example, students’ use of drawing as a tool to think through and refine their ideas based on new evidence.

While the focus of the instructional interventions in this study targeted drawing-to-reason, all purposes of drawing are valuable for learning in the classroom, and inclusion of drawing during instruction will often target multiple purposes (Ainsworth et al., 2011). During the methods course, Eileen’s and Reece’s use of drawing appeared to be process-oriented because they used drawing as a thinking tool to make meaning about the water-force phenomenon. In their interviews, Eileen shared that “drawing pushed [her] thinking deeper,”
while Reece commented that “[she] could just draw whatever [she] was thinking and then go back throughout the semester and edit [her] drawing.” However, Avery and Joan appeared to have more product-oriented purposes for their drawings during the methods course, such as organizing and recording content from hands-on activities and externalizing science knowledge for the instructor to assess. During her interview, Joan shared that in her drawing she was trying to “illustrate what we had talked about in class” and that “if [they] had not drawn, [she] would’ve probably lost some of the knowledge that’s in [her] picture.” Avery’s comments during her interview suggested she was using her drawings to remember content and build vocabulary. For example, she perceived challenges with drawing were “... specifically the more scientific vocabulary terms, it would be a bit easier to write out those definitions and verbally explain it in writing rather than trying to draw it out.”

The difference in how the PSTs used drawings may reflect their prior experiences with drawing as part of their science education. While all four PSTs had taken similar science content and methods courses prior to this study, their shared prior experiences with drawing varied. Neither Eileen nor Reece appeared to have had prior educational experiences with drawing that had been positive or valuable for their learning. However, both Avery and Joan shared specific examples of drawing from their undergraduate coursework that appeared to have influenced their use of drawing. For example, Avery’s focus on labeling and vocabulary reflected drawing instruction from her fall science methods course for the early grades. She discussed that they “did do quite a bit of [drawing], when [my instructor] would do demonstrations of experiments and things like that, we would put ourselves in the shoes of the students to be able to draw and label pictures.” Joan’s focus on communicating her content knowledge seemed to reflect her physics professor’s incorporation of drawing as part of their homework to show their solutions to
assigned force and motion problems. She shared that when they” did the [ATLAST force & motion] assessments that … in class, [she] recognized a lot of the drawings because [she] had done them the two semesters prior.”

In addition, their prior educational experiences may have influenced their beliefs about how science knowledge is generated, which could have influenced how they used drawing for their own learning. The formative assessment probe “Doing Science” (Keeley, 2010) was used at the beginning of the semester to learn about the PSTs’ beliefs for how science knowledge is generated. The probe revealed differences in beliefs among the four PSTs. For example, Avery’s focus on methodical generation of knowledge through experimentation was consistent with her more product-oriented purpose for drawing. Reece recognized a range of methods through which scientists learn, which was consistent with her more process-oriented purpose for her drawings as tool for reasoning about the water-force phenomena.

**Explicit Instruction Supported PSTs’ Use of Drawings Based on Metacognition.**

Metacognition refers to the PSTs’ self-awareness of the quality and utility of their generated drawing as a model of the represented phenomenon (Quillin & Thomas, 2015). The quality and utility of a drawing does not refer to its aesthetics or artistic attributes, but rather the relevance, completeness, and accuracy of ideas included in the drawing. Fiorella and Mayer (2016) described metacognition for generative modes of learning like drawing to be “knowing which information to select, what kind of knowledge structure to build, and which prior knowledge to activate during learning” (p. 719). In this study, the model aspect of metacognition was operationalized based on PSTs’ additions or changes to drawings as the lessons progressed, indications in their drawings about uncertainties regarding their explanations for the phenomenon, including question marks or stated wonderings, and responses during interviews.
about the extent of their understanding about the water-force phenomenon. The explicit
instruction on drawing-to-reason appeared to support both the PSTs’ metacognition regarding
their conceptual understanding about intermolecular water forces and how the practice of
drawing supported their learning.

The modeling intervention during the lessons supported PSTs’ evaluation of their initial
ideas and revisions. The PSTs revised their drawings based on both content from lesson activities
and instructor prompts. This reflects recognition that their prior drawing versions were missing
concepts needed to explain the water-force phenomenon. In addition, the drawings provided a
way for the PSTs to indicate questions that they still wondered about the phenomenon, in
contrast to their written explanation in which they only communicated ideas that they thought
explained the water-force phenomenon. Their interview responses reflected their lingering
uncertainty indicated in their drawings; all four PSTs commented about not being sure that their
drawings contained ideas that fully explained the phenomenon. As mentioned for the conceptual
knowledge learning outcomes, none of the PSTs included the difference in the balance of forces
among cohesion, adhesion, and gravity on earth versus in space.

One noteworthy finding regarding metacognition was evidence from the interviews of a
growth mindset among the PSTs at the end of the semester. Eileen, Joan, and Reece all discussed
that while they recognized limitations in their conceptual knowledge, they felt more confident
about physical science instruction because they recognized as teachers they will continue to learn
alongside their students. Nixon et al. (2019) have noted the likely role of self-directed learning
on elementary teachers’ knowledge for science instruction. They conducted an exploratory factor
analysis of fifth and sixth grade teachers’ responses on a science assessment instrument that
covered content relevant to their grade standards. Their analysis indicated an increase in SK with
years of experience up to mid-career teachers (7-18 years of experience), which they attributed to
everyday teaching experiences and lesson preparation but not formal professional development,
because it was limited for the teachers in the study. A structural equation model of the SK
assessment data by Smith et al. (2022) showed that years of experience teaching in their specific
grade level was a significant predictor of SK along with STEB. Other factors such as
professional development, science content courses during teacher education, and hours teaching
science in the classroom were latent variables influencing SK through the teachers’ STEB. Based
on their findings, Smith et al. recommended teacher education programs help PSTs recognize
that their learning will continue into their in-service practice.

The modeling intervention also supported the PSTs’ metacognition about the practice of
drawing to support their learning. All four PSTs commented during their interviews about
finding the practice of evaluating and revising their drawings valuable. For example, Joan
commented that “it was really helpful, rather than starting a new drawing every time,” because
she “was able to think through [her] stuff.” As mentioned in the discussion of the purposes for
drawing, Eileen noted that “drawing pushed [her] thinking deeper.”

This recognition of how drawing-to-reason challenged and supported the PSTs’ learning
is consistent with findings from studies in which drawing has been used as a generative learning
strategy to support expository text comprehension during science lessons. In a study with
undergraduate students in a biology course studying the human circulatory system (Kiyokawa et
al., 2012), the students who had to draw diagrams of the system after reading expository text
showed greater understanding of the concepts based on post-instruction assessments. However,
the drawing students perceived the material as being more difficult than students who had been
instructed to either summarize the readings in written text or were not give specific instructional
guidance for how to summarize the readings. The authors attributed the higher perceived
difficulty by the drawing students as metacognitive awareness of their understanding after
reading. Hellenbrand et al. (2019) tracked the eye movements of eighth and ninth grade German
students who were tasked to either draw pictures based on expository text about the influenza
virus as they were reading versus students who just read text that also included illustrations. The
eye movement of the students in the drawing group indicated more rereading of the text while
generating their drawings, and they had significantly higher post-reading scores on the retention
test and a drawing test on the text content. Hellebrand et al. attributed the learning outcomes to
the influence of drawing on their metacognitive awareness while reading. Schleinschok et al.
(2017) found that post-test performance and judgement of learning while reading were higher for
German undergraduate students who generated drawings about the formation of the polar lights
while reading, which they attributed to more accurate metacognitive monitoring.

**PST-generated Drawings Were Valuable for Assessing Learning Outcomes**

In addition to supporting the PSTs’ SK learning outcomes, another valuable aspect of
PST-generated drawings in this research was their affordances as assessment tools for the
instructor. Science education research into PSTs’ SK often focuses on what they do not know,
such as gaps in their physical science knowledge or alternate conceptions (Burgoon et al., 2010;
Harrell & Subramanina, 2014; Van Driel et. al., 2014), which is a deficit lens through which to
view elementary PSTs (Gray et al., 2022). In this research, the drawings allowed for a richer and
more assets-based view about the PSTs’ evolving knowledge, which was not revealed by the
ATLAST instrument. Text-based assessment focused on recall of factual knowledge may limit
communication regarding the accuracy and extent of student ideas. Frankel (2020) found that
asking undergraduate students to draw their explanations was a more accurate assessment of
their understandings of various science phenomenon compared to factual recall on multiple choice tests. Tobias (1993) found that undergraduate students focus on buzz words during science courses to pass examinations without conceptually understanding of the content, which was reflected in this study by Eileen’s comment that “sometimes you're able to write around the question a little bit. You can't really do that when you're drawing.”

The value of drawing to provide a more extensive assessment of students’ science ideas has been noted by other science education research studies. For example, Stieff and DeSutter (2021) discussed that the learning gains from sketching in chemistry are not necessarily captured by traditional, multiple-choice assessments. In their study, students who participated in a chemistry curriculum that included sketching as a modeling activity were more likely to include sketches of their ideas on assessments and to have more canonically accurate sketches, such as inclusion of the dynamics of particle movement, than students who did not have instructional support for sketching. Of relevance to this dissertation research, Cooper et al. (2015; 2017) reported that drawings produced by undergraduates in STEM majors provided more robust information about their understanding of intermolecular water forces compared with their written explanations. Cooper and colleagues attributed it to the students’ abilities to use drawing to depict structural and spatial information that is relevant for understanding cohesion and adhesion, which is consistent with findings for the PSTs.

Drawing as an alternate measure of PSTs’ SK also has been noted in other studies that have incorporated drawing along with more traditional assessments (Aydeniz & Brown, 2010; Harrell et al., 2022). Aydeniz & Brown (2010) found that PSTs’ drawings provided a better understanding about their conceptual ideas regarding electrical circuits, lunar phases, and seasonal changes. They used initial drawings to identify a range of alternate conceptions that the
PSTs had at the beginning of a science methods course. Their methods course incorporated a series of hands-on activities and discussions targeting relevant content to address the PSTs’ conceptions. Comparison of pre- and post-lesson drawings indicated changes in the PSTs’ ideas. Harrell et al. (2022) used drawing as one form of assessment for PSTs’ understanding of buoyant force after instructional interventions based on the 5E learning cycle to target SK during their science methods course. At the end of the lessons, PSTs were asked to draw a depiction of a boat floating on water with all associated forces acting on it. The drawings showed gains in PSTs’ understanding of the roles of opposing forces and surface area in buoyancy.

Unfortunately, the studies tended to focus on the lack of alignment of PST-generated drawings with canonical science explanations versus a more assets-based view of what they revealed about the PSTs’ knowledge and how to build on that knowledge to support their teaching practices. For example, in the study by Aydeniz & Brown (2010), although the post-test results showed significant changes in the PSTs’ ideas about circuits, lunar phases, and seasons, the authors elaborated more on the PSTs’ alternate conceptions, which were presumably from their initial drawings. The findings and discussion were unclear which ideas changed after the instructional interventions and how their instruction best supported PSTs’ SK growth. In their discussion of findings, Harrell et al. (2022) focused on the alternate conceptions that the PSTs still held, “documenting the persistence of serious alternate conceptions about floating and sinking” (p. 299). They stated that the PSTs’ SK aligned with preschoolers’, elementary students’ and middle school students’ ideas and alternate conceptions of buoyant forces (Biddulph et al., 1983; Hsin & Wu, 2011, Kohn 1993; Yin et al., 2005). Drawings have also been used to assess limitations in elementary PSTs’ knowledge of the digestive system (Oren & Ormanci, 2014) and nutrition (Reinoso & Delgado-Iglesias, 2020).
Interestingly, some studies that have focused on deficits in PSTs’ SK have not provided context for how PSTs’ knowledge compares with other non-education undergraduate students (Aydeniz & Brown, 2010; Crawley et al., 1988; Harrell et al., 2022), which gives the impression that elementary education majors have less robust science knowledge than their peers. This view reinforces the damaging narrative that “he who can, does; and he who cannot, teaches” (Bernard Show, 1903, as cited in Shulman, 1986, p. 4), which depicts the field of elementary education as less valuable and rigorous as a career pursuit.

Research studies that have included non-education majors as part of their assessment of SK show evidence that alternate conceptions noted for PSTs are common among all undergraduate students. For example, McDermott et al. (2006) investigated how a curriculum called Physics by Inquiry (PBI) might be beneficial to develop the conceptual understanding needed to lead instruction for elementary and secondary students. In the assessments, non-education majors scored lower than the PSTs. For example, in response to a question on acceleration of a ball rolling up and down an inclined ramp, 50% of the PSTs drew correct sketches of the acceleration vectors compared to only 20% of general introductory students. In a group of undergraduate students during their first to third year at an Israeli university that includes PST education, Trumper (2003) did not find differences between science and non-science majors on a written examination assessing astronomy knowledge. While there appeared to be differences in specific ideas related to greenhouse effects, Groves and Pugh (1999) reported that both education majors and science-related majors do not have strong understandings about greenhouse effects.

**Significance of SK Learning Outcomes**

This study contributes to a limited body of research on the use of drawing to target PSTs’
SK learning outcomes during their teacher education program. Science education research has shown that instructional support is influential on student learning when drawing is incorporated as a generative strategy in the classroom (Fiorella & Zhang, 2018; Leutner & Schmeck, 2021). Findings from this study with PSTs are consistent with other student groups and provide evidence that incorporation of explicit instruction on drawing-to-reason can support PSTs’ SK learning outcomes during their science methods courses. Teachers with more robust SK incorporate quality science instruction that is aligned with reform-oriented practices in the classroom (Brobst et al., 2017) and can be instrumental to students’ science achievement (Diamond et al., 2014). PSTs in this study constructed new conceptual knowledge connected to big ideas that transcend the boundaries of specific life, earth, and physical science strands (Harlen, 2010).

The PSTs also learned about the practice of drawing-to-reason for building knowledge based on the model use aspects of model relationships, purpose and salient features, and metacognition. National science research and educational agencies have stressed the importance of engaging children in authentic science practices while learning content (NRC, 2012), and findings from this study with drawing-to-reason suggest that PSTs benefit as well. While all four PSTs appeared to vary in the purpose for their drawings during the science methods course, drawings contribute to student learning from a range of product- to process-oriented roles in the classroom (Ainsworth et al., 2011). In this study, the PSTs’ prior education experiences with drawings appeared to have influenced the purpose for their drawings.

As discussed for the affective characteristics, findings from this study also support the use of Quillin and Thomas’s (2015) instructional framework for drawing-to-reason to build PSTs’ SK during in science methods courses as part of their teacher education programs. Quillin
and Thomas developed their framework for undergraduate biology students to gain model expertise with drawing-to-reason because of its value as an authentic science practice for building knowledge. While they proposed that the interventions would be applicable to fields outside of biology, this study was a novel application of the framework for elementary PSTs to target their learning outcomes.

Finally, this study serves an a more asset-based view of PSTs’ SK to highlight the knowledge they bring to their teaching practice and can build on, versus deficits in the understanding. The analysis of the PSTs’ drawings served as a tool to assess their conceptual knowledge and provided a richer view of the extent of their understanding about the water-force phenomena. While multiple-choice tests can provide quantitative measures for recall of factual knowledge, they may limit PSTs’ ability to reveal what they do know, as well as reinforce the idea that science is a collection of facts versus a means to understand the natural world. While written tests with open-ended responses may allow more flexibility for students to communicate their ideas, there can still be limitations due to science vocabulary. In addition, as seen with the PSTs’ written versus drawn explanations, some science ideas, such structural properties, are communicated more easily through visual representations. Researchers such as Akaygun and Jones (2014) and Tversky (2001) have advocated for the value of both written and visual representations for supporting students’ ability to communicate their ideas.

**PCK Learning Outcomes**

PCK was the final learning outcome of interest for the science methods course with explicit instruction on drawing-to-reason. PSTs’ science lesson plans and interview responses regarding lesson planning and facilitation during field experiences were used to explore how their instructional practices might support elementary students’ use of drawing as a science
modeling practice. Findings for this case study based on the content analysis of PSTs’ lesson plans and end-of-semester interviews included increased incorporation of drawing as a science instructional strategy and use of instructional practices that mirrored interventions from the science methods course and that could support model use of drawing by elementary students. While the PSTs incorporated interventions from the methods course in their own science instruction, their purposes for their own students’ drawings varied, which mirrored PSTs’ purpose for their own learning. Finally, their instructional practices, and purposes for drawing during their field experiences were influenced by factors such as time limitations and possibly by their beliefs about science learning.

**PSTs Incorporated Drawing in Science Lessons after Explicit Instruction**

Based on analysis of the lesson plans and the interviews, the explicit instruction on drawing-to-reason during the science methods class supported the PSTs’ inclusion of drawing as an instructional strategy in their own lessons. For the first science lesson focused on implementing a Paige Keeley formative assessment probe (Keeley, 2018) in their field placement classrooms, only half of the PSTs included an opportunity for the students to draw. Avery included drawing in her first lesson as a modality for students to communicate their ideas, and Eileen included materials during her lesson for the students to draw, but the purpose was not specified.

However, in their second lesson with the discrepant event demonstration, all four PSTs incorporated drawing as part of the lesson activities. The inclusion of drawing was influenced by the explicit instruction on drawing-to-reason during the methods course based on the PSTs’ responses during their interviews. During their discussions about their second lesson plan and instruction, they shared incorporating instructional interventions from the methods course in their
lessons and how they recognized the value of drawing for their students. In addition, PSTs, who participated in a similarly structured science methods course, which covered the same science and teaching content but did not include explicit instruction on drawing-to-reason, did not include drawing in their first lesson (Leavens & Davis, 2023). In the second lesson, some of these PSTs did include a drawing as an activity in their second lesson plan but did not include any instructional guidance.

PSTs Incorporated Interventions from Methods Course in Their Instruction

During their interviews, the PSTs specifically mentioned how they modeled their incorporation of drawing in their own lessons based on the explicit instruction of drawing-to-reason during the science methods course, particularly the visual literacy and modeling interventions. The graphic symbols that were introduced as part of visual literacy were the most frequently mentioned intervention during the interview. For example, when Avery discussed what she had learned about science instruction by focusing on drawing, she discussed the “magnifying glass zooming in.” Eileen shared how she had used “all the resources about drawing that [they] had learned” for her second lesson on with the “Cloud in a Bottle” phenomenon (Science World, n.d.). Joan created graphic organizers to support her students’ use of temporal frames. Reece’s incorporation of drawing in her second lesson reflected many of the explicit instructions on drawing-to-reason from the methods course, including student encouragement, visual literacy instruction, and opportunities to evaluate and revise original drawings.

Findings that the instructional interventions from the methods course influence the PSTs’ practices in the field are consistent with recent education research recommending teacher preparation for use of drawing in science instruction. For example, Areljung et al. (2021) used activity theory to explore how early childhood teachers in Sweden incorporated drawing in their
classrooms. They found that most of the teachers viewed drawing as a general tool to support learning or communication in the classroom but did not consider it as a learning strategy for science. For the small subgroup of teachers who did incorporate drawing in their science lessons, most did not provide explicit support for their students’ use of drawing. Areljung and colleagues recommended the need for teacher education and professional development for drawing as an instructional strategy in science based on their findings.

**PSTs’ Drawing Instruction Supported Model Use by Elementary Students**

Because the PSTs based their own instruction on the interventions from the methods course, the ways in which PSTs incorporated drawings in their second lesson would be more likely to support their students’ developing more expert model use of drawing to build SK. For example, Avery incorporated teacher prompts during the exploration phase of her 3E lesson with the film canister rockets to encourage her students to include non-observable, salient features in their drawings to explain their ideas about the phenomenon. Eileen incorporated graphic organizers and questions to help students focus on drawing non-observable structures, processes, and relationships to explain the phenomenon versus observable details, included limited visual literacy instructional interventions, and used student-generated drawings as the focus of small group discussions. Joan’s graphic organizers were intended to help students focus on salient features of the demonstrated phenomenon versus repetitively drawing the same observable feature. Reece was also intentional with prompts to encourage students to draw more salient, non-observable features, as well as demonstrating how to use the graphic symbols for drawing-to-reason.

However, one limitation for this finding is the lack of observations of the PSTs’ science teaching in the field or measures of their elementary students’ learning outcomes. While the
PSTs did collect their students’ drawings from their lessons as part of their reflections, they were not used for a source of data in this study because of lack of assent and consent from the elementary students and their parents or guardians.

**PSTs’ Instructional Purposes for Drawing in Their Science Lessons Varied**

Consistent with the use of drawing for their own learning, PSTs varied in how they incorporated drawing in their own plans. Joan and Avery appeared to use drawing with a more product-oriented purpose, such as drawing-to-communicate and drawing-to-learn, while Eileen and Reece were categorized as using drawing for a more process-oriented purpose, such as drawing-to-reason. For example, Avery and Joan used drawings mainly for students to record their answers, whereas both Eileen and Reece included guidance on the foundational images and scale tools for their students and opportunities for their students to update their drawings. Eileen and Reece used the words “student understanding” and “student ideas” when discussing drawing in their lesson plans during the interviews, whereas Joan and Avery used “student observations”, “answers”, and “correct labeling” in discussions of drawing in their lessons.

As seen in the analysis of lesson plans and from interviews, PSTs incorporated drawing in their plans and actual lessons in more ways that would support elementary students more expert use of drawing-to-reason based on the different model aspects of focus for this study. Joan and Avery appeared to use drawing for a more product-oriented purpose such assessment of student understanding or learning, while Eileen and Reece used drawing for a more process-oriented purpose for students to reason about phenomena. Eileen and Reece used the words “student understanding” and “student ideas” when discussing drawing in their lesson plans, whereas Joan and Avery used “student observations”, “answers”, and “correct labeling” in discussions of drawing in their lesson.
Factors Influencing PSTs’ Instructional Use of Drawing

While the explicit instruction on drawing-to-reason supported the PSTs’ PCK learning outcomes about drawing as an instructional strategy in science, several factors were noted from their interview responses, which may have limited how the incorporated and facilitated drawing for their lessons. Several PSTs discussed how time for their lessons prevented them from incorporating some of the visual literacy and modeling interventions that had been demonstrated during the science methods course. For example, Eileen shared “if we had given them more time to revise their drawings…their drawings could have been even better too.” Therefore, coordination of the lesson content and allotted instructional time with mentor teachers in the field will be important to allow the PSTs adequate time to incorporate drawing in ways that reflect practices demonstrated in their methods courses. In addition, based on the study design, the instructor did not provide guidance or feedback on drawing in the draft lesson plans, so that the PSTs’ plans represented their independent ideas, which likely reflected both the explicit instruction from the methods course and their prior science experiences. Therefore, more guidance and feedback during the planning process would likely be valuable to help PSTs incorporate drawing as a process-oriented tool for reasoning.

As mentioned for SK learning outcomes, one factor that may warrant further exploration is how PSTs’ prior science experiences may have influenced how they viewed the use of drawing as an instructional strategy. An epistemological framework refers to a collection of knowledge and beliefs that can be activated during learning situations and shapes an individual’s understanding in a particular context of what is the nature of knowledge and what it means to know something. Epistemological framing was introduced into education research by Hammer and Elby (2003), who explored how physics students’ epistemological framing influenced their
learning in the classroom. In the classroom a teacher’s epistemological framing helps them make sense of whether learning is occurring from their instruction and can vary based on the situation (Chakrin & Campbell, 2022). For example, the teacher could have an epistemological framing that only students with correct answers to teacher-posed questions are measures of acquired knowledge and learning versus noticing students’ ideas and how they are changing as an indication of learning. Russ and Luna (2013) noted how different epistemological framings can affect teachers noticing of student ideas, and that the same individual teachers can have different framing depending on the context.

In this study the PSTs’ epistemological framing during the science methods course about what it means to know something and how they valued that knowledge could potentially have contributed to the ways they used drawing both for building their own knowledge and as an instructional strategy. Joan and Avery’s focus on getting their explanations correct may have limited them to viewing drawing as a product to communicate answers or to assess learning. They were less likely than the other two PSTs in the study, Eileen, and Reece, to indicate what they wondered or questioned in their drawings of the intermolecular water force phenomenon, and they tended to focus on making sure students were answering correctly and creating detailed and labeled drawings.

Teachers’ beliefs about why it is important to include certain content influences that way in which it is taught. If PSTs are more teacher-focused and concerned with academic rigor, they may be more likely to use drawing only as an indicator of learning the correct answer, versus as an epistemic tool for building knowledge in which learning could be reflected in conceptual change (Edens and Potter, 2003). While there are multiple, important purposes for using drawings in the elementary classroom (Ainsworth et al., 2011), we also want teachers able to use
drawing as a tool for reasoning, which mirrors how scientists and engineers use drawing for thinking (NRC, 2012). If elementary teachers privilege the notion of correct facts and the accumulation of content knowledge, their students will not develop views and knowledge consistent with reformed-based notions of science as a way of knowing about the world versus a static set of facts to be memorized.

**Significance of PCK Learning Outcomes**

The findings from this study on drawing-to-reason contribute to limited research that addresses the need to support elementary PSTs’ knowledge of drawing as an instructional strategy in science (Areljung et al, 2021;2022). After explicit instruction on drawing-to-reason, PSTs who had engaged with drawing during the methods course were not only more likely to include drawing in their science lessons (Leavens & Davis, 2023), but to incorporate it in ways that would support their students’ more expert model use of drawing to make meaning about science phenomena. The inclusion of drawing instruction in their own teaching during their field experiences is consistent with their learning outcomes regarding affective characteristics towards drawing. Their more positive attitudes towards drawing and recognition of its value were likely influential on their enacted teaching practices.

The findings of how the PSTs’ implemented drawing in their science lessons is consistent with the literature concerning the influential role of science teacher educators on PSTs’ own instructional practices (Lunenberg et al., 2007). The PSTs based their own drawing instruction for their field experiences on the instructional interventions demonstrated in the science methods course. While half the PSTs included drawing in their first field experience, which coincided with the initial lessons on drawing-to-reason, they did not incorporate any of the instructional
interventions from the science methods course. However, in the second field experience lesson, all four PSTs included at least one of instructional interventions from the course.

As discussed for the affective characteristics and SK learning outcomes, the PCK learning outcomes from this study support Quillin and Thomas’s (2015) framework as a guide for explicit instruction on drawing-to-reason with elementary PSTs during their science methods course. All three interventions, including affective, visual literacy, and modeling, appeared to influence the PCK learning outcomes. In addition, this study also identified additional factors that influenced whether and how PSTs use drawing as an instructional strategy in science. Including prior educational experiences, beliefs about how science knowledge is acquired, and contextual factors in the classroom, such as time limitations, which will be important to consider during instruction on drawing.

Study Limitations

While this study identified several potential benefits of explicit instruction on drawing-to-reason for elementary PSTs, there were several limitations in the study’s design and data analysis. The limitations listed below provide additional context for the transferability of the findings to other scenarios.

There were a few limitations to findings based on the quantitative data strands for this mixed methods study. The small number of participants limited the data analysis of the survey and assessment instruments to descriptive comparisons versus performing inferential analysis with the data. While the science methods section with drawing instruction did include eleven PSTs, only five consented to participate in the study. Of the five who consented, only the four who were present for all the lessons on the water-force phenomena and did pencil and paper drawings were included as embedded subunits for the case study. In addition, two of the
instruments used for generating quantitative data, including the SDA instrument and the
ATLAST force & motion assessment, were used outside of the population for which they were
developed, so the reported external validity and reliability may not be applicable for elementary
PSTs.

In addition, the researcher did not have access to individuals who could serve as coders
for an interrater reliability check for the content analysis of the various artefacts, including
drawings, interviews, and lesson plans. However, the researcher did incorporate several other
measures to establish trustworthiness of the study interpretations, including the use of member
checks with the participating PSTs and peer debriefings with her advisor at various stages during
structuring of the category matrices for the deductive content analysis of the data artefacts in the
study.

In this study, the researcher served as the instructor of record for the methods course,
which may have had an impact on data from interviews if PSTs responded in ways that they
anticipated were desired by the researcher versus sharing their true thoughts and ideas. This issue
was addressed in part by the researcher, who as the instructor was proactive and intentional in
establishing relationships with the PSTs in both the science methods course, as well as, during
the prior semester in an engineering methods course in which the researcher was also the PSTs’
instructor. The instructor’s actions during the course, which were described in Chapter Three’s
Trustworthiness section, were meant to minimize the inherent power differential between the
PSTs and the instructor, so that the instructor was viewed more as a partner in their learning
(Dobransky & Frymier, 2004). In addition, the use of a mixed methods research design in which
the deductive content analysis from the interviews was triangulated with data from survey
instruments and other data artefacts was also a measure of credibility regarding interpretation of
the PSTs’ interview responses.

As noted in the discussion of the learning outcome regarding affective characteristics and
SK, the changes in STEB and conceptual knowledge about intermolecular water forces may be
attributable to multiple activities and content consistent with ambitious science teaching
(Windschitl et al., 2018) from the science methods course. Leavens and Davis (2023) found that
PSTs who participated in a section of the science methods course that did not include drawing
instruction also reported increased measures of STEB by the end of the semester. However, the
PSTs from the drawing group were more likely than their non-drawing peers to incorporate
drawing in their field experience lessons.

There were also external factors that may have influenced the PCK learning outcomes in
the study. The issue of time for actual implementation of lessons during field experiences in the
elementary classroom was not considered and may have limited the extent of PSTs’
incorporation of drawing in their instruction. Multiple PSTs commented in their interviews both
about how time limited their actual versus planned instruction, as well as how they observed
limited incorporation of science in the elementary classroom in general. Some of the PSTs were
given less than optimal times to facilitate the lessons in which they had included plans for
drawing, including after school assemblies because the students would be too distracted to lead
lessons in other content areas. At least one had to squeeze in the lesson after lunch because of
lack of instructional time for science during the remainder of the day.

The PSTs also observed limited to no science instruction during their in-field
experiences. While they observed some use of drawing for mathematical instruction, they did not
observe its incorporation as a thinking tool in the classroom. It can be difficult to bridge research
to practice when there is a lack of examples and use in the field. Teachers’ environmental context is an influential factor for their instructional practices.

**Implication of Findings for Elementary Science Methods Courses**

“If teachers are to use conceptual teaching methods in their own classrooms, they need to learn content and pedagogy through the same conceptually based methods reformers are advocating be used with grade school students.” (Stofflet & Staddard, 1994; p.32). The findings from this study support the benefit of including explicit instruction on drawing-to-reason during elementary PSTs’ science methods courses to influence their affective characteristics, SK and PCK for including drawing as an instructional strategy in the elementary science classroom.

The PSTs’ learning outcomes in this study support the use of Quillin and Thomas’s (2015) framework to structure the drawing instruction interventions during the methods course. The affective, visual literacy, and modeling interventions were all mentioned by the PSTs during interviews as being influential on their learning during the semester. The instructor’s demonstration for the use of the graphic symbols and the opportunity to evaluate and revise drawings were mentioned as impactful on both the PSTs’ own learning, as well as for instruction of their own lessons. While Quillin and Thomas’s framework was conceptualized originally for use with biology undergraduate students, they argued that it was applicable for building model expertise in other fields, which findings from this study support. A recent article by Karlberg et al. (2021) provided guidelines for elementary teachers to incorporate drawing as a learning strategy in the classroom, which they based on their own experiences implementing drawing according to Quillin and Thomas’s framework.

In addition, this study supports the use of PST-generated drawings during science methods courses to provide an asset-based assessment of their SK and to serve as a learning
strategy to construct knowledge that is authentic to science practices (NRC, 2012). Education research that has focused solely on the lack of depth in PSTs’ SK and their alternate conceptions does not add substantively to collective knowledge about effective elementary teacher education practices and tends to view elementary PSTs through a deficit lens (Van Driel et. al., 2014). As seen in this study, the assessment instrument, ATLAST (Horizons Research, Inc, 2011), did not capture evidence of conceptual learning that was noted from the PSTs’ drawings and written explanations of the intermolecular water force phenomenon. Teacher educators can use drawing during science methods courses to obtain an understanding of both the PSTs’ prior knowledge and their SK learning, which can guide their instruction during the course.

One aspect of drawing that was not explicitly discussed during the science methods course in this study was the different purposes for incorporation of drawing in the classroom. As noted from the assessment of both SK and PCK learning outcomes, the PSTs appeared to use drawing for different purposes, which likely reflected their prior educational experiences and beliefs about how knowledge is acquired. Therefore, the PSTs would likely benefit from discussion and demonstrations of the various purposes for drawing in science, in addition to drawing-to-reason, as well as guidance during their own lesson planning for when and how to incorporate each type. For example, the use of drawing as an assessment tool by the teacher educator could be used as a model for the PSTs’ own practice with their students.

**Future Work**

Future directions for this work include expanding this exploratory study to include more participants in science methods courses with explicit instruction on drawing-to-reason to better assess the significance of the initial findings in this work. While it may not be possible to discern differences in STEB due to drawing instruction, more participants would allow use of inferential
statistics for assessing learning outcomes based on quantitative measures. In addition, for this study, the evaluation and revision updates were individual activities for the PSTs during the lessons. This design was intentional to explore how each individual PST independently used drawing and made meaning from the activities, but future work should include opportunities for group discussions and modeling based on interactions with peers. In addition, studies that include field observations of the PSTs’ science instruction would provide opportunities to explore how instructor feedback and guidance may influence PSTs’ implementation of drawing in their own practices. Finally, longitudinal studies to observe classroom instruction of in-service teachers who participated in a science methods course with drawing instruction will be needed to determine if the benefits noted during their teacher education program continue to influence their enacted PCK during their teaching careers, as well as the contextual factors that influence their science teaching practices with drawing.
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APPENDICES
Appendix A

ATLAST Force & Motion Multiple-Choice Assessments (Horizons Research Inc., 2011)

The assessment was developed by the Assessing Teacher Learning About Science Teaching (ATLAST) project at Horizon Research, Inc. ATLAST was funded by the National Science Foundation under grant number DUE-0335328. The multiple-choice questions addressed the sub-ideas about force & motion listed below. The questions were also based on three types of knowledge, a) knowledge of science content (Level 1) b) using content knowledge to analyze/diagnose student thinking (Level 2), and c) using content knowledge to make instructional decisions (Level 3). The specific questions cannot be included in this dissertation based on the terms of agreement with Horizon Inc. Information for how to request the multiple-choice assessment with questions for use in research studies can be obtained from www.horizon-research.com/atlast/(last accessed 9/23). A summary of the number of questions addressing each sub-idea and level of knowledge are listed in Tables A-1 for the multiple-choice questions.

Sub-idea A- A force is a push or pull interaction between two objects, and has both magnitude and direction

Sub-idea B- All of the forces acting on an object combine through vector addition into a net force; they either balance each other out (net force is zero) or act like an unbalanced force (net force is not zero)

Sub-Idea C-A force diagram uses arrows to represent the forces acting on an object at a particular moment. The length of the arrow represents the relative magnitude of the force. The direction of the arrow represents the direction of the force acting on the object.

Sub-Idea D- If an object is moving faster and faster, then there is a net force acting on the object in the same direction as the motion
Sub-Idea E - If an object is moving faster and faster, then there is a net force acting on the object in the same direction as the motion.

Sub-idea 1 - If an object has constant speed in a straight line (or zero speed), then there is no net force acting on the object. This can occur either when the forces on the object are balanced or there are no forces exerted on the object.

Sub-idea J - The force of friction acts to oppose the relative motion of two objects in contact. Friction acts on both objects along the surfaces in contact with each other. The magnitude of friction depends upon the properties of the surfaces and how hard the objects are pushed together.

Table A-1

Multiple Choice Questions

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<th>Question Number</th>
<th>Primary Sub-Idea</th>
<th>Secondary Sub-Ideas</th>
<th>Knowledge Type Level</th>
<th>Best Answer Key Used in Assessment</th>
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<td>26</td>
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<td>27</td>
<td>A &amp; J</td>
<td>C</td>
<td>1</td>
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<td>29</td>
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<td>1</td>
<td>C</td>
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Appendix B

T-STEM INSTRUMENT

STEB Questions

1. I am continually improving my science teaching practice.
2. I know the steps necessary to teach science effectively.
3. I am confident that I can explain to students why science experiments work.
4. I am confident that I can teach science effectively.
5. I wonder if I have the necessary skills to teach science.
6. I understand science concepts well enough to be effective in teaching science.
7. Given a choice, I would invite a colleague to evaluate my science teaching.
8. I am confident that I can answer students’ science questions.
9. When a student has difficulty understanding a science concept, I am confident that I know how to help the student understand it better.
10. When teaching science, I am confident enough to welcome student questions.
11. I know what to do to increase student interest in science.
Appendix C

Semantic Differential Attitude Survey Instrument

Below is the list of bipolar adjectives that were used in the Semantic Differential Attitude Survey (Bauer, 2008). The PSTs responded to the list of adjectives for the following statements for science disciplines and practices, a) “Physical Science is…”, b) “Biological Science is…”, c) “Earth Science is…”, d) “Science Drawing is…”, e) “Science Investigation is…”, and e) “Science Observation is…”.

<table>
<thead>
<tr>
<th>Adjective</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
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<td>easy</td>
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<td>comprehensible</td>
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<td>disgusting</td>
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<td>comfortable</td>
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<td>worthwhile</td>
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<td>chaotic</td>
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<td>insecure</td>
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</tbody>
</table>

hard
beneficial
boring
simple
clear
bad
frustrating
fun
incomprehensible
not challenging
unpleasant
dull
attractive
uncomfortable
useless
play
organized
dangerous
relaxed
secure
Appendix D

Semi-structured Interview Questions

Questions to better understand how incorporation of drawing during the science methods influenced the PSTs’ affective characteristics, science conceptual knowledge, and pedagogical content knowledge.

A. PEDAGOGICAL CONTENT KNOWLEDGE Questions

Orientation towards teaching science:

1. How do you think students best learn about science?

2. In what ways did your ideas about teaching science change over this semester?

Knowledge about Instructional Strategies

1. What are some ways that you think drawing might be useful as a science teaching strategy to facilitate student learning?

2. What do you think students might have difficulty with regarding drawing in science?

3. I’ve shared links to your two fieldwork lesson plans from this past Spring’s 2 Redirect Weeks. *Let’s start by looking at the lesson plan for Redirect Week 1. As you look through this plan, can you share what resources or learning experiences influenced the activities and assessments that you included in it?

   Probing:
   a. Could you say more about…?
   b. Could you elaborate on the reasons why?

   [Repeat the sequence from * but reword to “Now let’s look at the lesson for Redirect Week 2].

4. What, if anything, did you learn about science teaching & learning from focusing on drawing in science this semester?

   Probing:
   a. What makes you think that?
   b. Can you give some examples?

5. In what ways has the focus on drawing in science this semester influenced your knowledge of students’ thinking?

   Probing:
B. SCIENCE CONCEPTUAL KNOWLEDGE Questions

1. I've created a file that has the series of drawings that you created during our lessons about intermolecular water forces this semester. I've been looking at them to see what you included, and it would help me to hear you talk about them. First, I'd like to look at your final drawing. Will you say a little about "What is your drawing trying to show?"

2. Now let's take a look at how your drawings changed over time. "Will you help me understand why you made certain changes to your drawings over time?"

3. In what ways do you think drawing your explanation affected what you wrote for an explanation in your notebook?

4. Were there aspects of your understanding about the water forces that were helpful to draw?

   **Probing:**
   a. Could you say more about…?

5. What aspects of your understanding about the water forces were easier to write?

   **Probing:**
   a. Could you say more about…?

C. AFFECTIVE CHARACTERISTICS Questions

Now that you have finished the semester…

1. How prepared do you feel for teaching the 3 strands of science, life sciences, earth sciences, and physical sciences, in the elementary classroom?

   **Probing:**
   a. In what ways do you feel well prepared?
   b. In what ways do you feel like you need more preparation?
   c. Can you say more about whether your feelings of preparation differ based on the science strand?
   d. Can you say more about why you feel this way?

2. Do you envision incorporating drawing as a learning strategy in your own teaching?

   **Probing:**
   a. Can you say more about why (or why not)?
   b. How do you think you would incorporate them?
3. How did you feel about drawing for your own learning this semester?

Probing:

a. Can you say more about some ways that you found it challenging?
b. Can you say more about the ways you may have found it beneficial to you?
c. Can you say more about how your attitude may have changed over the semester?
### Appendix E

Perceptual Inventory of the PSTs’ Final Version of Drawn Explanations of Water-Force Phenomenon

<table>
<thead>
<tr>
<th>Participant</th>
<th>Researcher Drawing Notes</th>
<th>Researcher Science Concept Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avery</td>
<td>• Horizontal orientation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Divided contrast for earth vs space</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Drew line vertically to divide</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Total drawing (image and text) top 2/3 of paper</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Image just in 1/3 of drawing</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Drawing and text occupy approximately the top half of the paper with the remainder as white space</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Different format for headings on earth vs space</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Space lettering smaller than earth</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Washcloth drawn larger for space than earth</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Squiggly lines for outline of washcloth to indicate applied force?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Faint pencil marks on earth washcloth-maybe to indicate water layer</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Thick layer around watch cloth in space</td>
<td></td>
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<tr>
<td></td>
<td>• Up and down curved arrows to indicate twisting (labeled)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Downward vertical arrows to indicate falling due to gravity (labeled)</td>
<td></td>
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<tr>
<td></td>
<td>• Gravity arrows drawn in middle of droplets</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Traditional teardrop water droplets in two rows spaced evenly apart on earth</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Drops just fall down- not container shown</td>
<td></td>
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<tr>
<td></td>
<td>• Traditional tear-shaped water droplets in layer on washcloth in space to indicate the layer as water (also labeled)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Magnification foundation image used to show water molecules as particles (foundational image)</td>
<td></td>
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<tr>
<td></td>
<td>• Magnification tool used to show model for water both as a 2D atom</td>
<td></td>
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<tr>
<td></td>
<td>• Gravity is a force pulling down</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Typical alternate conception of zero gravity in space</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Water composed of particles</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Molecular and charge structure of water</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Verbal use of force vocabulary but no indication of visual understanding</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Does student think adhesion only present on earth and cohesion only present in space? Question about why there is a layer of water sticking to washcloth indicates not a full understanding of phenomenon.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Uses language wrung out with force arrows but not necessarily connected to understanding that it is forcing water off of the cloth fibers</td>
<td></td>
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<tr>
<td></td>
<td>• No indication about the role of the balance of forces except the recognition of difference in gravity on earth vs space</td>
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<tr>
<td></td>
<td>• Correct terminology use for adhesion and cohesion (text not visual explanation)</td>
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<tr>
<td><strong>Eileen</strong></td>
<td><strong>Gravett</strong></td>
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<tr>
<td>Folded paper in half for earth v space (latitudinal-hamburger fold)</td>
<td>Gravity is a force that pulls objects downward</td>
<td></td>
</tr>
<tr>
<td>Horizontal orientation to drawing</td>
<td>No gravity concept of space</td>
<td></td>
</tr>
<tr>
<td>Contrast earth of left with space on right</td>
<td>Alternate conception about spatial arrangement of molecules in space compared to earth to explain difference in observations</td>
<td></td>
</tr>
<tr>
<td>Labeled title on each side (left orientation and similar format)</td>
<td>Possible idea about balance of forces indicated (adhesion vs gravity)</td>
<td></td>
</tr>
<tr>
<td>Included tub for water to fall into</td>
<td>Only considers adhesion of water molecules to washcloth as a force in addition to gravity</td>
<td></td>
</tr>
<tr>
<td>Indicated water in tub with a wavy line</td>
<td>Doesn’t write about or draw cohesive forces</td>
<td></td>
</tr>
<tr>
<td>Faint line used to indicate the top of the tub while the sides and bottom are bolder line (likely to show that it is open at the top)</td>
<td></td>
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<tr>
<td>Title for Space side slightly smaller</td>
<td></td>
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</tr>
<tr>
<td>Bold dark lines used when labeling for force arrows and for foundational images (appears foregrounded)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lighter/more narrow lines for washcloth</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Included particle images, magnification tool and arrow vectors</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- No drawn indication of molecules interacting (text description only)
- Neat block style labeling of images
- Incorporation of scientific vocabulary: adhesion (earth only) vs cohesion (space only)
- Cohesion had indications of erasure
- Includes questions about the phenomenon
- Labeling dark and bold pencil markings
- Downward arrows are dark and bold markings
- Magnification image is dark and bold (appears more foregrounded)
- Twisting arrows and wash lighter more narrow pencil marks (seems more backgrounded)
• Force arrows for twist are curved and in opposite directions
• Gravity arrows are straight down- 2 on either end of wash cloth close to depicted water droplets
• Water droplets are traditional tear-shaped
• Gravity arrows are drawn below the washcloth and not connected to it
• Drawing in top third of paper
• White space (no text or drawings on half of paper)
• Spatial indication of particles different on earth side than space side and labeled to explain conception of molecules closer together in space
• Used magnification tool to indicate water being composed of particles
• Added a magnification tool to also depict the molecular structure of water as balls and sticks with labeled atoms and charges
• Added magnification tool to visually draw a ball and stick water molecule attracted to the washcloth
• Washcloth in magnification tool just a flat line
• Washcloth on earth smaller than space and shaded gray likely to indicate it is damp (which is labeled)
• Water layer on washcloth in space drawn as a later of circles around cloth
• Force of adhesion in space indicated with arrows oriented from particles to the washcloth center (vs on earth where indicated with magnification tool)
• Faint diagonal lines drawn on washcloth on earth and in space
• Hypothesis written that washcloth has a positive charge (but just for space, not indicated for earth)
• Magnification tool used to how a positive charge for washcloth in space
| Joan | Gravity is a force that pulls objects downward  
|      | Force applied to washcloth affects water molecules  
|      | Alternate conception of no gravity in space  
|      | Although no overall force diagram seems to have be trying to show a balance of forces responsible for observed behavior in space  
|      | Forces are responsible for observations vs spatial arrangement of particles  
|      | However  
|      | Not clear if understanding that the polarity of water molecules is present regardless if on earth or in space  
|      | Trying to pull in an unclear idea of gas composition on earth vs space  
|      | Confused vocabulary definitions but depicted the interactions correctly | • Horizontal orientation  
|      | Folded paper in half for 2 sides  
|      | Earth on left/space on right  
|      | Titles for each side left top orientation  
|      | Titles same size, same format, underlined and have colons to indexically indicate information below it  
|      | Drawings and text take up 2/3 of paper  
|      | Washcloth drawing in top third  
|      | Larger washcloth for space than on earth  
|      | Added small drawings around main washcloth for additional explanation-majority are below the washcloth depiction  
|      | Labels, symbols drawing foundational images are bolder and thicker lines  
|      | Washcloth slightly lighter lines  
|      | Earth drawn below washcloth is lighter with bold magnification image for oxygen  
|      | Liquid drawn as wavy line in containers  
|      | Foundational images include magnification tool, particles, and line vectors  
|      | Used curved lines in opposite directions to indicate twisting  
|      | Indicated twisting forces present everywhere on cloth with dashed lines for behind washcloth based on field of vision from the front side.  
|      | Dashed lines slightly lighter and thinner than solid lines for twisting  
|      | Calls twisting a squeeze force  
|      | Writes about water molecules in spaces around washcloth threads  
|      | Vertical downward lines used for gravity.  
|      | A line for gravity drawn on each of the depicted water droplets  
|      | Lines to show intermolecular water forces and attraction of water to hand |
- Slightly curved arrows used indexically to label objects or link ideas together
- Used brackets to group visual ideas together or visual and text together
- Traditional tear shape for water droplet.
- Depicts stages of water falling off washcloth
- No depiction of container that water falls into
- Particles in magnification for water same on earth as space.
- Used magnification tool to show
  - Water made of particles
  - Washcloth as a solid
  - Molecular structure
  - Intermolecular water forces
  - Oxygen as textual symbol
  - Charge on person

- Water particles spatial arrangement in magnification view same on earth as space
- Depicts water molecule as ball and stick
  - Uses just letter symbols to label molecules on earth
  - Includes letter symbols and charges in space
- Depicted washcloth as large open spaces like a puzzle
- Included water particles on washcloth magnification on earth but not in space
- Confused vocabulary for adhesion vs cohesion on washcloth but correct for penny drawing
- Text about liquid properties positioned under title above washcloth
- Text about no gravity in space positioned under title and above washcloth
<table>
<thead>
<tr>
<th>Reece</th>
<th>Questions written in smaller text than labeling of images or information that is stated with certainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal orientation</td>
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<tr>
<td>Drew line to divide paper into 2 spaces</td>
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<tr>
<td>Drew in top 1/3 of paper</td>
<td></td>
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<tr>
<td>Drawing plus text takes up half of vertical space (bottom ½ white space)</td>
<td></td>
</tr>
<tr>
<td>Labeled each side same format approximately same size for earth vs space (earth on left)</td>
<td></td>
</tr>
<tr>
<td>Washcloth is drawn as irregular oblong shape with wavy border</td>
<td></td>
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<tr>
<td>Drawing for space seems larger and is positioned higher than image for earth</td>
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<tr>
<td>Labels, lines, and shapes are all bold with thick lines</td>
<td></td>
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<tr>
<td>Symbolic labels for force smaller size than other labels</td>
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</tr>
<tr>
<td>Water drops both ovals and tear drops</td>
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<tr>
<td>Labeled gravity on one drop and depicted as larger and unbalanced with air resistance</td>
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<tr>
<td>Question about the role of air resistance</td>
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<td>Water not depicted as falling into a container</td>
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<tr>
<td>Foundational images included</td>
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<tr>
<td>- Magnification</td>
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<tr>
<td>- Vector arrows</td>
<td></td>
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<tr>
<td>- Particles</td>
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<tr>
<td>Charges indicated on washcloth in space but not earth although adhesion force indicated in both</td>
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<tr>
<td>Washcloth on earth shaped with light pencil squiggle to show damp</td>
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<tr>
<td>Water drops drawn on outside</td>
<td></td>
</tr>
<tr>
<td>Alternate conception of no gravity in space</td>
<td></td>
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<td>Balance/unbalanced forces as cause</td>
<td></td>
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<tr>
<td>Force of adhesion balances gravity</td>
<td></td>
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<tr>
<td>Doesn’t recognize force acting between molecules</td>
<td></td>
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<tr>
<td>Different particle density and spatial arrangement of molecules in different states of matter</td>
<td></td>
</tr>
<tr>
<td>Attraction between negative and positive charges</td>
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<tr>
<td>Hands apply force to washcloth</td>
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</tbody>
</table>
• Shows balance of forces (adhesion vs gravity on earth) and vectors indicate relative size of force
• Magnification tool used to show
  o Particle makeup of matter
  o Molecular structure of water
• Liquid and solid contrasted in magnification based on spatial arrangement of particles
• Magnification of water molecule structure from a water droplet on earth and the water layer in space
• Water molecule drawn as ball and stick 2D model with labeled atoms and with charge distribution (both on earth and in space)
• Doesn’t include depiction of water molecules interacting with each other and has a question listed as to if there are forces keeping water molecules together
• Drew a gravity arrow above and oriented towards the washcloth on earth with a question mark
• Curved arrow vectors used to indicate force of hands on washcloth
• Straight arrows down for gravity. One on a water droplet and a second one on the washcloth used for a force balance indication
• Straight vectors for force of adhesion drawn all around washcloth in space in the layer used to indicate water
• Used water droplets as symbol in layer around washcloth in space to indicate it is the water layer as well as label as water (word) and the textual symbolic H2O
• Lines without arrows used to indexically label
• Question about charges and attraction of water molecules to washcloth (which was drawn with positive charges all inside the outline)
Appendix F

Avery’s Interview Transcript

Interviewer (00:07):
Okay, so Avery, before we get started, I just want to affirm that you are consenting to be recorded for the purposes of this research.

Avery (00:17):
Yes, that is correct.

Interviewer (00:18):
Okay, thanks. So, now that the semester's done, I have different groups of questions. This first group of questions is related to what we call pedagogical content knowledge, so, knowledge for teaching science. My first question is: how do you think students best learn about science?

Avery (00:39):
I think that students are able to best learn about science by doing. I don't know if that makes sense, but, through hands-on experiences, I think students can watch a video of somebody else doing an experiment, or they can read a passage explaining scientific concepts. But, when they're able to physically do an experiment or see how a scientific idea works, I think that will stick with them, and that they will better be able to learn and build that foundation and build upon different scientific topics by doing experiments and other hands-on activities.

Interviewer (01:22):
Okay, nice. You shared how you think they learn best. So, in what ways might your ideas about teaching science have changed over the semester?

Avery (01:38):
I think with this semester specifically and working with older students, I was in a third-grade class. Just with the content that we learned in class, I think that learning how to best meet the needs of students when their scientific content ... I think, with older students, it seemed a little bit daunting at first like, "Some of these scientific ideas, I don't even know if I fully understand them to be able to explain to students." But, being able to use specific strategies to help those students, I think that's something that really helped me this semester, was using drawings. That was a way to be able to take these ideas that seemed a little bit daunting at first like, "I don't really know if I can," for students to be able to understand this. I don't know if I can just do it by verbally saying it, but drawing pictures on the board for them, then having the students draw their own pictures to be able to help explain their ideas to be able to better understand their thinking.

Interviewer (02:52):
Thanks, that's great. You lay right into my next question. What are some ways that you think drawing might be useful as a science teaching strategy to facilitate student learning?
Avery (03:07):
Like I was saying before with certain ideas, just verbally explaining them, even for myself, it's kind of hard to visualize that if a teacher's just explaining it or if even you watch a video of it, it can be a little bit tricky. But, being able to draw your ideas out is just a way to be able to visualize the concepts that you're learning and to be able to grow upon that. Oftentimes we refer back to the video of the astronaut in space bringing out the washcloth. To be able to build upon that idea and go back and add to our drawings, which was something that I really liked that we did because it allowed ... It wasn't just a onetime, "Okay, here's a drawing to help get your ideas out." But, it was a way for us to build upon that knowledge and even understand, "Okay, I didn't have maybe the correct idea at first with this drawing," but, to be able to refer back to that to be able to see how your thinking has changed.

Interviewer (04:17):
Okay, that's really good. What do you think students might have difficulty with regarding drawing in science.

Avery (04:27):
I think some concepts could be a little bit tricky to be able to understand. I know in my third-grade class they were in, for their last unit, they were working on plants. You think back to if they're learning about photosynthesis and being able to understand what happens inside the plant, being able to draw that might be ... Just because they can't see that, it might be a little bit difficult to understand how to draw that and represent something so small in a bigger picture and understand that this is what it looks like inside a plant, but not being able to physically see that.

Interviewer (05:17):
Some of the spatial aspects and knowing what to draw could be challenging. So, we've talked a little bit about your drawing in instruction. I want to look at a couple of the coursework materials that you created for helping your instruction. Let's take a look. I know it's been a while since you've seen it, so you can pull it up and look at it really quickly. I want to look at your lesson plan for redirect week one first if you want to share that. And then, take a few minutes to look through it to reorient yourself as to what you included in it. And then, I'll share what question I have that I want you to talk about.

Avery (06:00):
Yeah [inaudible 00:06:04]

Interviewer (06:10):
That one's your second one. Do you have your first one?

Avery (06:13):
Yes, sorry [inaudible 00:06:17] here let me ... sorry, the share screen is being in the way. Let's try that again.

Interviewer (06:28):
Yeah, I discovered when I did my proposal that I think if I share off of my second screen, it makes it really tiny. I have to make sure it's on my-

Avery (08:27):
Oh, yeah.

Avery (08:28):
All right, [inaudible 00:08:28]

Interviewer (08:29):
Yeah, it's hard to ... I didn't want to send them beforehand because I didn't want there to be a difference in time for when people looked at them. I knew it would take a few minutes because we're remembering what we did. As you look through this plan with me, I'd be interested in you sharing what resources or learning experiences from this semester influenced the different activities and assessments that you included in it.

Avery (08:56):
Definitely for this lesson, we wanted to emphasize students referring back to drawings and using those drawings to be able to help represent their ideas. Something that a lot of students in our class used quite frequently were their whiteboards, and the students really did, any time they got to use their whiteboards, enjoy being able to draw on those. When we read aloud the different statements with the students, we encouraged them to use their whiteboards to be able to visually represent the different ideas. Specifically one that we wanted to emphasize was the difference between the earth spinning and moving because that's a little bit tricky to understand.

Avery (09:50):
One thing that we did after giving students a little bit of time to draw their own ideas was we wanted to also include a visual representation, which is something that I know that we use oftentimes in our course this semester. But, we had a flashlight. And then, we used a basketball to represent the earth, and we had the flashlight to represent the difference between the earth spinning versus if it didn't move as it orbited the sun. I think that was something that helped the students to be able to visualize that to see that instead of just verbally explaining it. Some of the students might have still been a little bit confused about that.

Avery (10:49):
And then, the students, when we asked them to share their responses, it's something that we hadn't written in the lesson plan, but a lot of them were eager to come up to the board and drawn their pictures that they had represented on their smaller whiteboards and then recreate that picture on the larger whiteboard for their other peers to see. I think having that visual representation of drawing it on the board helped the other students to be able to better understand the thoughts of their peers of what they thought was the ... what statement from the probing thing.

Interviewer (11:39):
The drawing on the board, did one student draw; and then the others looked at their drawing? Did they add to it or just-

Avery (11:47):
Yeah, students, once they ... Even some of the students added ... One student even added ... This wasn't in the probe, but even added the moon orbiting the earth, so it was different aspects that the students were able to think about, about how there are different factors that affect the way that the earth moves.

Interviewer (12:18):
You talked about the whiteboards being something that your teacher was already incorporating. Was drawing something that was familiar to them, or had they mainly used the whiteboards for just writing numbers?

Avery (12:34):
I would say they mostly used their whiteboards for math, so it was more just for writing and answering questions. But, I'm trying to think. I know definitely during the second redirect week, I was able to see quite a few science lessons as the students worked on their unit on plants. I was able to see quite a few drawings for that one and a lot of drawing pictures and then labeling them and things like that.

Interviewer (13:17):
So, it was something that your teacher incorporated that you saw in addition to what we did in class.

Avery (13:22):
Yeah.

Interviewer (13:23):
Okay, awesome. Anything else you want to add about this first lesson plan?

Avery (13:33):
I think that's it. One thing that I think that was a little tricky when going about it is trying our best not to emphasize that we didn't want the students just to select the correct answer. For a lot of lessons in school, that's the goal, but we wanted them just to be able to think like scientists and use evidence and drawings to be able to represent their ideas.

Interviewer (14:04):
Okay, sounds good. Was the idea of having students explain their own thinking and having a best answer, was that new for you?

Avery (14:19):
Yeah, I think with this lesson, a lot of when we were first going over the statements from the probe, a lot of the students were very quickly, "Oh yeah, I think it's that one. That one makes
sense," but then guiding them along to be like, "Okay, why? What's the evidence or justification for why that makes sense?"

Interviewer (14:43):
Okay, let's take a look at your second redirect week lesson, and we're going to do the same thing. Take a few minutes to reorient yourself to what you did with the can rockets. Then, we'll talk about what resources or activities influenced what you included in your lesson plan.

Avery (14:58):
All right.

Interviewer (16:02):
Okay, so basically, it's the same type of questions, not same type of questions, same question. As you look through the plan, share what resources or learning experiences influenced the activities and the assessments you included in the lesson plan?

Avery (16:17):
I think for this lesson, a big part of it was students making observations, and specifically when we went outside to launch the rockets and to be able to do that. I think something that, if we were to do this lesson again, is, when we did go outside, we told students things to look for like how fast ... How long does it take the rocket to launch? How high does it go? Making note of the different amount of ... We gave different groups a different amount of the Alka-Seltzer tablets. What's the difference between half a tablet versus a full one or if we do two tablets? A big part of it was making those observations. And then, we did have a worksheet for them to fill out once we got back into the classroom where they drew a picture of the rockets launching and what they thought was happening inside the rocket and what it looked like when it launched.

Avery (17:25):
Maybe something I would do is I would have the students bring out the worksheet with them on maybe a clipboard or something like that so they could make those observations while they're watching them just to be able to keep them engaged and focused while the groups were working. A big part of it was making observations to be able to understand how the experiment worked, and then again, drawing pictures when we had the students fill out that observation sheet. Like I said, we had them fill out what was happening inside the rocket, and then what the launches looked like. Again, I think those pictures helped the students to explain how they thought this experiment worked because we know, after filling out their observation sheet, we asked the students, "What have you observed? How do you think this experiment worked?"

Avery (18:27):
I think being able to reference back to those drawings that they created helped them to be able to explain what they observed and how they thought it was able to work. Something, too, for this experiment that I think did go well is that having the students ... just being flexible when working with the students. When we were out there, a student asked, "What happens if we do one-and-a-half tablets?" That wasn't something that Candy and I were planning on doing, but we were like,
"All right, let's see," so being open to taking that student input, and, if they have a question, being able to try it out and experiment.

Interviewer (19:20):
See what works. When you-

Avery (19:23):
Oh, yep.

Interviewer (19:23):
No, go ahead.

Avery (19:24):
And then also then having students to be able to think a little bit deeper, this wasn't ... This was an experiment that we could build upon. If they ran multiple days, these are some other things we could have done, but then having students be able to think a little bit deeper, at the end, we asked them questions like, "How do you think water temperature would affect the rocket launches?" We did answer this one a bit, the size of the tablets, but how much difference in water? Because, we added the same amount of water to each one. The canisters were pretty small, but even if we could affect maybe the height of how high the rockets go by adding parts to make it more of a rocket.

Interviewer (20:21):
Yeah, instead of just cans. I see the fins that you have on here. When you were talking about the drawing, having them draw their ideas, did you guys provide any specific instruction, or they were just drawing based on their background knowledge of drawing?

Avery (20:40):
I would say mostly just based on their background knowledge of drawing. For the picture of what is happening inside the film canister, we did have a picture of a film canister on there so it was a little bit easier for them to be able to draw exactly what was going on inside. But, I would say most of it was based off of just what they observed and what background knowledge they had.

Interviewer (21:10):
When they were explaining their thinking, did they tend to refer to their drawings as they explained?

Avery (21:16):
Yeah, and I would say that was something that we encouraged as they were explaining their thinking of why they thought that the rockets were able to launch. We encouraged them to refer back and be like, "Okay, what did you draw in your picture? How does that help explain what you're ..." trying to verbally explain, going back to that drawing.
Interviewer (21:43):
What was your thinking for the reason to do that?

Avery (21:51):
Part of it, too, is we didn't want the students to feel like they drew their observations just for drawing them, but to be able to show them that there was a reason that we wanted them to be able to refer back, or there was a reason we wanted them to draw their pictures or draw their understanding to be able to refer back to it and not just have it as a time for students to be like, "Okay, we're just going to draw for fun." It is fun and the students do enjoy that, but being able to help show them that there's a reason for doing it, to be able to help them verbalize their understanding.

Interviewer (22:35):
Nice, nice, thanks. I got to make sure I don't miss anything because I'll get excited and skip over my questions. Anything else you'd want to add about your lesson plans before we move on?

Avery (22:52):
I think that's all for this one.

Interviewer (22:55):
That sounds good. You can stop sharing because I know you're probably looking at that and not... That's a bad thing because sometimes it can feel weird talking to a screen. Moving on, what do you think, if anything, you learned about science teaching from focusing on drawing this semester?

Avery (23:27):
A lot of times, I think back to that one handout where it had the different aspects you can use for drawing. Specifically, I think of the one where it showed a magnifying glass zooming in and specifically labeling pictures and things like that to be able to help students feel like it's important to understand that there's a purpose for their drawing and that there's different ways to use drawings in the classroom to be able to help them understand that there's a purpose why they're doing those drawings. It can help. I think those specific strategies for the students can help them better understand, even going back to what I was saying earlier about students maybe not understanding quite the space of drawing, using the plants. You could use that magnifying to be able to help students understand, "Okay, this is what's happening inside a plant." Even if we're not able to see that, you could use a drawing like that to be [inaudible 00:24:44]

Interviewer (24:44):
That sounds good and those are some really good examples. That gets at some of my probing questions. This, you may have already answered in some ways. You focusing on drawing in science influenced your knowledge and understanding of student thinking. You used drawings. You were drawing. You incorporate it. How did that influence you thinking, your knowing about what students think?
Avery (25:11):
I think that drawings, it's something that can be used as a formative assessment to be able to collect those and be able to see a student's thinking or see their understanding. If they have a drawing that is very detailed and labeled, you're able to see their understanding of that topic versus maybe if it's a drawing that ... collect observation sheets from students and it's a drawing that maybe isn't quite correct, you'd be able to know that that student needs a bit of extra support to be able to understand that topic.

Avery (25:56):
I enjoyed looking back after both of the lessons for redirect week one and two, being able to collect those worksheets to be able to see students understanding and just being able to understand their thinking. Time-wise, I wasn't able to ask every student to explain their thinking and verbally explain to see their understanding, so it was good to be able to have those drawings to get a better understanding of what students know.

Interviewer (26:30):
Those are nice examples. That sounds great. What I'm going to do now is transition. We've been thinking about the teaching science. What I want to do now is think about the actual content, so science content knowledge. The file that I shared with you that is a series of drawings, if you want to share that, we're going to take a look at your drawings this semester. We're thinking about your science content knowledge.

Avery (27:00):
[inaudible 00:27:00]

Interviewer (27:01):
Probably the best way to go is to do the slideshow so it makes it larger. And then, we're going to start by looking at your final picture, so the very last slide. Awesome. I've been looking at them to see what you've included. But, one thing that would help me as I'm looking at these for my research is to hear you talk about them. I'd like to hear you tell me a little bit about what your drawing is trying to show.

Avery (27:37):
For this drawing, yeah, I split it on half where, on the left is the washcloth on earth, and then on the right with the washcloth in space. In the middle, we have the washcloth. And then, these arrows represent the direction of it being rung out. We have the water droplets falling down because of gravity on earth pulling the water down, and then using, like I mentioned before that, the magnifying tool to be able to represent what the inside of the water molecules look like. Let's see, come on over here. And then, as we saw in the video of the washcloth being rung out in space, we saw that the water droplets did not fall down like they would on earth. Instead, they almost created a layer around the washcloth.

Avery (28:38):
We began representing those water molecules or using the magnifying tool to represent that those water molecules do look the same in space, but how there's no gravitational force to pull them down. I think a difference too is then adding a bit more scientific terms. You can see here cohesion and adhesion, including those terms, but also still asking a bit of questions for, I think just here on the washcloth in space. That's maybe something, when we're doing drawings, you think of labeling them and writing ideas out. That was something I didn't originally think to add, but, in a drawing, we could add questions. That was something that I did add in my drawing.

Interviewer (29:48):
You've probably spoken to this, but the magnification, your knowledge of that, to use that, where did that come from?

Avery (29:59):
That did come from our science methods course. That was one of the strategies that we talked about, incorporating that into the drawing.

Interviewer (30:14):
And then, my other question, I think I know this. I don't think that you envisioned there being ... You've drawn separate droplets in that layer around the washcloth. My interpretation is you envision it as a layer, but you're showing the droplets, just thinking about that being water all connected together.

Avery (30:36):
Yes.

Interviewer (30:37):
Awesome. What I want to do now is go through the drawing series. If you go to the very first one that you drew, what I wanted to do is have you talk a little bit about helping me understand why you made certain changes to your drawings over time.

Avery (30:55):
I think a little bit what I said before, one of the biggest changes was adding a bit more of those scientific terms as we learned about them like adhesion and cohesion and being able to understand how the water molecules, how they stick together. I think, looking at-

Interviewer (31:24):
Unfortunately, the second one, I had sticky notes on it. I thought I took a picture with it out, but I guess I was thinking I wanted to have the sticky notes on there.

Avery (31:31):
I think the sticky notes, they did help when looking at the drawings to be able to understand the different things we can add to the pictures.
The biggest changes that I noticed when I looked through them were between the first and the second. That seemed to be what I observed, was you put ... The second one has the water molecule structure on there, and I'm assuming the second one was after we did the different types. We drew the two-dimensional representation for water molecules and we did the magnetic, and that was when I did the polarity of the water, bending the water. I saw the biggest changes here on that. And then, the next one I think is when you added in some vocabulary, if I remember correctly.

Avery (32:37):
Yes, that is correct.

Interviewer (32:37):
That was after we did ... Yes, we did the maze and the water drops on the pennies. That's when I introduced vocabulary.

Avery (32:47):
Yes.

Interviewer (32:48):
Okay, and that was the main thing that I noticed with the changes. You can affirm it seems that your changes reflect the actual activities that we did in the lessons.

Avery (33:08):
I would agree with that. I think when we would receive our drawings back, knowing that, using that information that we had discussed in class and learned about and knowing, "Okay, there's got to be some way this applies to ... There's a reason we're learning this," so it applies back to this drawing to be able to use.

Interviewer (33:32):
Sounds good. Let me make sure ... You can leave it up while we're looking at it. You did your final drawing, and then I had you write the explanation in your notebook that you submitted on Padlet. I was wondering if you could speak to: in what ways do you think drawing your explanation affected what you wrote for an explanation in your notebook?

Avery (34:01):
I think the drawing definitely helped to be able to have a visual to be able to translate the ideas from what the drawing was to being able to write those out. It helped as a guide for what to include in the explanation to be able to mention or to know what to mention like, "Okay, we're going to mention about how there's no gravity in space to be able to pull the water droplets down," and knowing to write about the structure of the water molecules or what makes the water molecules stick together. So, being able to have that visual, it almost acted or did act like a guide to be able to know what to include.

Interviewer (34:55):
Were there aspects of your understanding of those water forces, so what was making a difference in space versus on earth, so aspects of your understanding about that that were helpful to be able to draw?

Avery (35:13):
Yes, I do think that being able to draw it was a way to represent what we observed from first watching the video, and being able to draw it was a good way to be able to help visualize my understanding of why this occurred instead of trying to write it all down in words in a way that we [inaudible 00:35:50] entirely understand from ... The first drawing is a bit easier to explore those ideas by drawing a picture instead of trying to write those ideas down that, at the beginning, I didn't have the clearest understanding of.

Interviewer (36:11):
So, just in general, expressing initial ideas overall was easier. Are there some aspects of the explanation that are easier to write than depicting them in drawing? Were there some things that you would have preferred just to write about?

Avery (36:32):
I think maybe for when it comes ... specifically the more scientific vocabulary terms, it would be a bit easier to write out those definitions and verbally explain it or in writing rather than trying to draw it out.

Interviewer (36:55):
Okay, yeah because you did those, so I didn't know if there was something. If you had to do an explanation, would you tend to draw that and if there's aspects of your explanation that you would just tend to write, is what those questions are getting at.

Avery (37:13):
Yeah.

Interviewer (37:16):
Let me make sure I haven't forgotten anything as I go through the questions. Okay so, the last one, it is moving on from not just water forces, but just thinking about force and motion in general. In what ways if any do you think your conceptual understanding of force and motion, so, force and motion in general, not just this water phenomenon, developed or changed over the semester?

Avery (37:59):
I don't know about this semester. When I think back specifically to force and motion, a lot of it comes back to the physics class we took, ooh, spring semester sophomore year. When I think back to that class, I think of a lot of the ... That was taken online because we were not in person that semester, but thinking back to a lot of the ideas we represented through drawings, and I think specifically with forces and motions, it's much easier to be able to see a picture of maybe a car moving and being able to see that force arrow and being able to use a drawing to be able to
represent that rather than reading on a page or reading an explanation that is written. It's much easier to visually be able to see that.

Interviewer (39:16):
I think Jordan mentioned it was a Zoom and there was a workbook that had a lot of drawings in it. Did you draw as part of that, or was it just looking at the drawings they had depicted?

Avery (39:32):
We definitely did do a lot of drawing in that class.

Interviewer (39:35):
For doing the force arrows and things like that, okay.

Avery (39:39):
Yes.

Interviewer (39:39):
I think I asked Jordan to share the workbook. I forget what work. She said it was a workbook, so I wanted to take a look and see what that looked like. That was helpful. Doing those drawings for that physics class was useful.

Avery (39:56):
Yes, definitely.

Interviewer (39:59):
Good to hear. I think that that's all. You can pull down your drawing if you want to now. We're done with that. That was thinking about your science content knowledge. This last section are thinking about affects, so attitudes and beliefs. Now that you've finished the semester, how prepared do you feel for teaching the three strands of science, so, life science, earth science and physical science in the elementary classroom? Speak to how prepared you feel for teaching those science strands.

Avery (40:32):
I think I do feel prepared. I think, for last semester and this semester, being able to see many demonstrations of how to incorporate hands-on lessons and experiments to be able to make it engaging for students, I think I do feel prepared for knowing what is the best way to have students be excited about science and ways for them to engage in the classroom. I would say maybe more on the content side, maybe a little less prepared, I think, specifically, like I said, for more older students and maybe with concepts that I still might feel a little ... that are maybe a little more complex, maybe just feeling a little bit less prepared for teaching that. But, I feel like I have all the means necessary to know how to have students be engaged in science and have them excited to learn.

Interviewer (41:48):
You actually answered, too. I wanted to know: in what ways do you feel well prepared, and then where do you think you need more preparation. You talked a little bit about the content, particularly for the upper grades. Do you think your feelings of preparation differ based on the science strand?

Avery (42:07):
Yes. I feel a little bit better about more earth and environmental and life sciences compared ... I think for me, physical science is a bit trickier.

Interviewer (42:24):
Why do you feel a little trickier about the physical science? Do you know?

Avery (42:29):
I think a part of it does go back when I think back to that physics class that we took spring semester sophomore year. It was a physics for elementary ed, so it definitely wasn't actual physics.

Interviewer (42:53):
But you were taking physics. It was targeted for the way that you needed it to [inaudible 00:43:01]

Avery (43:03):
I think when I think back to that course, the topics we learned, it wasn't something that just came naturally in a way. I guess when I think of physical science, I'm like, "This is something that's a little trickier," and I want to be able to explain it to students in a way that makes sense for them versus when I think of more life sciences; it's just a topic that, even for myself, I find a little bit more interesting. I think it's just a topic that maybe I'm a bit more excited to teach, so it's something that is a little bit less daunting when I think of it.

Interviewer (43:50):
Those are all valid. I'm trying to understand how different people feel different ways. Do you envision yourself incorporating drawing as a learning strategy in your own teaching one day?

Avery (44:05):
Yes, definitely, for sure. I think even in not just science but being able to incorporate drawing ideas or for students to be able to draw their ideas in science, but also taking that knowledge to other core subjects and being able to use drawings to be able to understand students' thinking.

Interviewer (44:33):
I can't remember which student mentioned that your math methods does a lot of visual thinking.

Avery (44:37):
Yes.
Interviewer (44:41):
It can be incorporated in multiple ways. And then, the final question is related to drawing for your own learning this semester. How did you feel about drawing in general for you during the class as you were learning?

Avery (44:55):
I think, like I said, it was a good way to be able to get my thinking, my understanding down on paper and being able to build upon that. I guess we could see that when looking at the progression of my drawings. There was a few times where I was looking at it and I was like, "What am I going to add?" Because I know I wanted to add to the drawing, but there was a few times where there was a little bit of a struggle to be able to figure out I knew that I wanted to add something to this drawing to be able to build upon it. But, there were a few times when I got a little stumped of what to add, if that makes-

Interviewer (45:51):
More to add, okay, that makes complete sense. That's one thing that you found challenging if you already felt like your explanation was fully illustrated. Was there anything else that you found challenging about drawing this semester?

Avery (46:18):
I would say that was the biggest challenge of maybe not ... There were times of not fully understanding a concept and then trying to add that to the drawing but not fully understanding of how to apply it to adding onto the drawing.

Interviewer (46:43):
Okay, we would learn something, but you weren't sure how that fit into the overall explanation. What are some ways that you may have found that drawing was beneficial to you?

Avery (46:59):
I think that it was easier. If there was a time when there was a little stump, it was easier to be able to look at the drawing and figure out a way of how to add and what we learned to the drawing. I think it was easier to do that visually than it would have been to do it in writing. I think that, if you're writing and you don't quite understand fully the concept, it can be tricky to be able to write that down. But in a drawing, I was able to visually see what we already had and what we were working with. Being able to visually see it was a bit easier.

Interviewer (47:46):
And then, this will speak to ... Did your attitude about drawing change over the course of the semester? How did you feel when you first started drawing at the beginning of the semester compared to how you felt about it at the end?

Avery (48:05):
I think one thing is that, by the end of the semester, it was okay to understand this drawing isn't going to be perfect. It's not going to be. I want to be able just to try my best to get my ideas
down, which, I think it can be when you think about asking a student to draw a picture of what they observe relating to a science topic. It can be a little bit tricky for someone to be like, "I don't really know how to draw this. I'm not a good artist. I don't know how to make this represent my ideas in a way that looks good," but understanding that it's not quite for the purpose of making this beautiful picture, but rather to be able to visually see those ideas and label pictures and things like that.

Interviewer (48:59):
Okay, that sounds good. I know you talked about the physics class, but in terms of drawing for science particularly, but drawing in general, had you been exposed to that very much in your educational background prior to this semester?

Avery (49:18):
I would say, definitely last semester, we did in the science methods course. We did do quite a bit of, when Ms. Sharon would do demonstrations of experiments and things like that, we would put ourselves in the shoes of the students to be able to draw and label pictures. But I would say, before that class, not too much.

Interviewer (49:44):
Okay, so, in your own education in general for learning, it would have been new except for the physics. There was the drawing with the physics I guess, too.

Avery (49:55):
Yeah, yeah.

Interviewer (49:55):
Okay, yeah, just trying to get a sense of your background or your exposures to drawing prior to this semester as we look at it. Well, I think that's it, Avery. Anything else that you want to add?

Avery (50:07):
I think that's it.

Interviewer (50:10):
I'm going to stop this really quickly.
Eileen’s Interview Transcript

Interviewer (00:07):
So Eileen, I just want to verify before we start the interview, that you do consent for being recorded for the purposes of this research.

Eileen (00:15):
Yes, I do.

Interviewer (00:16):
Okay, awesome. My questions are divided up into, there are three groups of information I'm trying to understand from the interview. The first is about pedagogical content knowledge. Knowledge about teaching science. My first question is, how do you think students best learn about science?

Eileen (00:41):
I'd say they best learn about science through getting a chance to do science, and then through questioning the students to see what they know, and try to get them to reach those conclusions.

Interviewer (00:56):
Okay, sounds good. What ways might your ideas about teaching science have changed over the semester?

Eileen (01:06):
I would say over this semester, and last semester, I see a bigger importance to having them do science. Because I think before, I didn't see that as much. Then this semester also taught me a lot more about drawing in science, which is also something that personally I didn't like in school. But I was also never really taught to do it like we were this semester. So that's something that's changed too.

Interviewer (01:32):
Okay, thanks for sharing. That's good to hear. Then that leads into the next question, because you brought up drawing. What are some ways that you think drawing might be useful as a science teaching strategy, that facilitates student learning?

Eileen (01:48):
I think it can help students label what they see, using the different scientific labeling skills that we talked about. I think it could also help you as the teacher see what they think is going on, and compare how deep their knowledge is, based on how much they're able to draw or show.

Interviewer (02:10):
Thinking about their thinking. Then with that, what do you think students might have difficulty with, regarding drawing in science?
Eileen (02:19):
I think they might have difficulty with drawing why it's happening, versus just drawing what they see happening in the experiment. Because that's something that I had difficulty with in the beginning, when we were doing our drawings.

Interviewer (02:32):
Okay, so it's relating it to your experience. What they might have trouble with. We've talked about what you think about instruction. One of the pieces of evidence or data I have for your actual instruction is your lesson plan. I've shared the two links. What I'd like to do first, is look at your lesson plan for redirect week one.

Eileen (02:55):
Okay.

Interviewer (02:55):
If you want to share that. I know it's been a while, that was your Page Keeley probe. I had to wait until the end of the semester to do the interviews, so that it didn't influence what you shared. But I know you might not be as familiar. So if you want to take a few minutes and just reorient yourself as to what you were doing with that, take a second, and let me know when you're ready to talk about it.

Eileen (03:15):
Okay, thank-you. Okay, I'm good now.

Interviewer (03:42):
Okay. What I want, you can just, as you go through, I want to have you share what resources or learning experiences that we did, or you had during the semester, that influenced what you included. So what activities and assessments you included in your actual lesson plan.

Eileen (04:02):
I'd say part of it was just doing the Keeley probes with the students, and not telling them the right answer right after explaining how it works. That was not something I thought to do before this class, this semester. Then I would say ... I'm just reading through it.

Interviewer (04:29):
Feel free. Take your time. I realize you haven't looked at it since February.

Eileen (04:38):
Then some of the questions that we asked also related to what we asked in class. Phrasing some of them as, "Why do you think that?", or, "What do you think is happening?" Then asking them, "What is happening?" That was I think the two biggest things from this lesson. At the end of our lesson, we also gave the students a chance to discuss why they thought, on whether the cookie crumbles weighed more or the whole cookie weighed more, with their partners. We had a few share out to the class. So that discussion piece.
Something we've also learned in the class is being strategic with who we pick to share their answers, and why. So students could hear what other students thought.

Interviewer (05:28):
Okay, so you thought it was important to have students communicate with each other. Could you say more about how you had them communicate? Did they talk? Or did you support them in any other way, with sharing their ideas?

Eileen (05:43):
Yes. I'm pretty sure we did ask them. We did have a paper. We originally were going to have them select their answer based on a Google form, and write why they thought that. But our Google form ended up not working on our study. But we had paper copies of the question, so they were able to circle the answer they thought was correct. Then they were able to hand write an explanation of why they thought that answer was best. But then we did have them do a think, pair, share discussion, where they verbally shared their thoughts with at least their partner, and then some shared with the whole class.

Interviewer (06:25):
What influenced you to think about a think, pair, share? Why'd you think that would be beneficial to have?

Eileen (06:33):
I would say that's probably from all of our classes. I think that's been a strategy that a lot of professors have told us is a good one to use. Then I personally like it, because it gives some of the students that extra wait time they need, to gather their thoughts. It also gives students who might not be comfortable sharing with the whole class, an opportunity to still share their answer with just a partner.

Interviewer (06:56):
Okay, that sounds good. Let's do the same thing with the second one. So pull up your second redirect week.

Eileen (07:02):
Okay.

Interviewer (07:03):
Take a few minutes, and just reorient yourself to what you were doing. I know that was a little closer to the end of the semester, but it's still been a little while. I'll eat my cookie while you read.

Eileen (08:10):
Okay, I'm ready whenever you are.

Interviewer (08:12):
Okay. Yeah, so the same thing. As we're going through it, just talk about some of the resources or activities that influenced what you included in your lesson plan.

Eileen (08:23):
Okay. I guess for this one, first we wanted to look, I guess something that influenced this lesson plan is making it interdisciplinary. Because the moment that we were doing this in our field placement classroom, they weren't doing science at that moment. They had switched to social studies. But we still wanted to try to make it connect to something they were learning, or about to learn. We knew they were starting a big EL unit about water. Being able to do some sort of science with them that related to water, and then of course connect it to the science standard, was the reasoning behind why we picked this probe.

For this one, we didn't have, since it was a describing event, we didn't have them actually do the science themselves. They did just watch us. But one of the students during our lesson asked to feel, not the bottle, but the pump, to see what happened with it. So we let them, the students that asked to touch that, we let them have that hands on experience.

A lot of our questioning in this section also came from, I think it was the textbook that we read. I can't remember the name. But it's Taking the Plunge maybe?

Interviewer (09:47):
Yeah, the Harlan-

Eileen (09:49):
Yes, the Harlan one. With a bunch of the different types of questioning. So we had some questions that I think were called attention focusing questions. Maybe, what happens when I add the rubbing alcohol to the bottle? Or, what do you see happening inside the bottle? To focus their attention on making sure they were looking at the bottle.

Then we also included some other questions. "Why do you think the cloud formed?" Then we also, this was another one where we did pull in drawing. So all the resources about drawing that we had learned. We had a graphic organizer for them, with a model of the bottle, and the stopper on top. Which, we should have adjusted that a little bit for the after portion. But we had them draw what was happening before we pulled the stopper out, and then after we pulled the stopper out, I'm pretty sure. We asked them questions about that. Like, "What could you add to your drawing of the event, to represent what was happening?"

I'm pretty sure, I can go, I don't think we ... Yes, we did make slides for this. We might have had, I'm trying to remember whether we ended up doing this or not. But we might have put in some of the different drawing ways that we did. But I don't think we ended up adding that part in.

Interviewer (11:28):
I do remember the graphic organizer, because I think I did comment about, you'd done the different bottles. I just asked if you could do the stopper out, so that it was clear that there had been a change. There's your before and after. So that was what was asked. Did you do any drawing instruction? Or they just drew, based on their prior knowledge of drawing?

Eileen (11:54):
I can't remember exactly. I know we had talked about possibly doing some drawing instruction. But I think we ended up not doing drawing instruction for this one. But I do think that could have been helpful to show.

Interviewer (12:09):
Then following up on that, is drawing something they had done in their classroom? Or was it a new experience for them? Do you know?

Eileen (12:20):
I am not sure about that. I can pull up the actual drawings through that they did. Because I'm trying to remember whether ... We definitely didn't show them all of the different drawing tools. But I feel like we did the one, the magnifying glass one, with that arrow. But let me look and see.

Interviewer (12:20):
Okay.

Eileen (13:14):
I don't think we gave them drawing instructions. But I do think we told them about drawing arrows maybe, because a lot of them do have arrows in their drawings that I'm looking at. So I think we did talk to them about labeling their drawings. We drew an arrow on the board, and explained that. A lot of them did label their drawings with the arrows after we told them about that. But that was the main drawing instruction that we gave them. I'm not sure if they've done drawing before in science. We actually didn't see a science lesson while we were there. So I'm not sure.

Interviewer (13:59):
Well it's interesting with that one that has, some of them did look like they were doing the magnification. But you said you didn't specifically show them to do that?

Eileen (14:10):
I don't think so.

Interviewer (14:12):
Okay. Could you say more of why you changed your mind about doing the drawing instruction, if you were thinking about it previously?

Eileen (14:22):
Honestly, I'm not really sure. I think I do remember the day that we had done the experiment, or the lesson. We had planned for 30 minutes to do it, and we ended up getting 15 to 20 minutes to do it. That could have been part of it. But yes, I am not 100% sure.

Interviewer (14:46):
If I had to hazard a guess, I would imagine it was a time limitation.
Eileen (14:51):
Yeah.

Interviewer (14:52):
I'm trying to remember. One of the groups, it was that the lesson ended up being, I don't remember if it was, they had to do it during lunchtime. Or if it was picture day. I remember there being some issue with a few of them.

Eileen (15:09):
I don't think that was ours. They had had an assembly though before ours. So they just got back late from that.

Interviewer (15:20):
I'm sure that they were very attentive.

Eileen (15:23):
Yeah, we knew we had to teach at least one thing on Monday after the assembly. We figured this would be the most likely to keep their interest, after having just done a fun assembly. We didn't want to make them sit down and do the reading assessment that we needed to give. They did really enjoy this lesson.

Interviewer (15:44):
That's good. That was a smart move on your guys' part, to do that. So, awesome. I think that's it with the lesson plans, so you can stop sharing if you want to.

Eileen (15:56):
Okay.

Interviewer (15:59):
You included the drawings. One of my questions is, what do you think, if anything, that you learned about teaching science this semester, due to focusing on drawing?

Eileen (16:17):
Something that I learned personally is not to stress about making the drawings perfect, or look nice. Because I learned that the point of the science drawings isn't necessarily to look nice, but to show what you're seeing. So that's something that I'll take to my students.

I know when I was a student, it would frustrate me that I couldn't get mine to look nice. It made me not want to do it. But then I think I've also learned how important the labeling of your drawings is, and the different drawing instructions that we could give kids. That is something that I do wish that we included with our cloud in the bottle experiment.

Because I was surprised and impressed with how much they were able to draw on their own. But I was thinking back, I think in your class we watched the Austin's Butterfly video. If we had given them more time to revise their drawings. Granted, it isn't our
class, so we couldn't really take that time to have it be a multiple day lesson. But I think their drawings could have been even better too, with that.

Interviewer (17:24):
Yeah, that's a nice addition. I was going to ask, my probing questions for that was, "What makes you think that? Give an example." You did both of those with your answer, so I think we're good. Then my final question with relation to the science teaching knowledge is, in what ways has the focus on drawing in science this semester influenced your knowledge of student thinking? How does drawing, like we drew in science, and was focusing on that this semester, how did it influence what you know about student thinking?

Eileen (18:05):
I think it can influence me to see how deep a student understands the concept. Because if they just drew, for the cloud in the bottle for example, the rubbing alcohol at the bottom, or just some swirls to represent the gas, and labeled that, I know what they see. But for the students who incorporated something about air temperature or pressure, which wasn't that many of them. But for the ones who did, I can tell that they have either a deeper understanding of what was happening, or at least they were trying to make those connections. Some of them weren't necessarily correct in what they put down, but I can see they were trying to think of the reason behind why the science was happening.

Interviewer (18:48):
Okay. The ones that aren't correct, do you think that that's useful knowledge? Even when it's incorrect?

Eileen (18:54):
Yes, I do. Because it still tells you that they're moving past the point of just understanding what they see in front of you. Then since you know that they're incorrect, you can help correct them. Whereas if you didn't know if they were incorrect or correct, you wouldn't know that you needed to help get them to that correct point of understanding.

Interviewer (19:15):
That's a good ... Yeah, thanks. That's a nice point. I'm going to transition us a little bit. We've been talking about teaching science. Now I want to think a little bit about our own, the content knowledge about science. The first thing that we're going to look at is, I created that series of drawings that you did over the semester. If you want to pull that up, we're going to take a look at those really quickly.

Because I've been looking at them for my own, looking to see what I think you understand, or what you included. But the one thing that would help me is to hear you talk about them. So go to the actual final drawing. That's the very last slide.

Eileen (19:56):
Okay.
Interviewer (19:56):
It probably would help to pull it up. If you do the slideshow, that'll make it bigger. That'll make it way better. Yes.

Eileen (20:07):
Can you see it up there?

Interviewer (20:08):
Mm-hmm, yeah. Thanks. That's great. The first thing I'd like to do is ask you to say just a little bit about what your drawing is trying to show.

Eileen (20:22):
I would say that my drawing's trying to show the differences between the wash cloth being wrung out on Earth, and how that looked, versus the wash cloth that we saw being wrung out in space.

Interviewer (20:31):
Okay. Looking at the different, what are some differences that you put on here? What are we looking at?

Eileen (20:40):
One big difference that I see is, on the Earth one, I see that we had the force of gravity acting on the water and the wash cloth. Whereas in space, there isn't gravity. So I marked that. Then on the water in space one, when I did the magnifying drawing technique, I drew the molecules as being closer together. Because it had a different texture almost in the space one. It looked more like a gel than a liquid. Whereas the one on Earth, it just dripped off. It looked wet.

Interviewer (21:28):
For a different thing. I think that's basically the bend that you were ... Because I noticed you drew a little rectangle with water. So that was the bend that we had underneath-

Eileen (21:39):
Yes, that was the bend that the water was falling back under.

Interviewer (21:42):
Yes, I thought that that was the case. Then I know that it likely is obvious, but you included the magnification tools. Where did you learn to do that?

Eileen (21:56):
I learned to do that in your class.

Interviewer (22:00):
It wasn't something that you had seen before, or you-
Eileen (22:04):
I don't think so. I might have seen it before, but I don't think I would have thought to use it.

Interviewer (22:10):
Okay. Awesome. So then, now we've seen, this is your final drawing. Go all the way back to the first drawing. What I was hoping is, I guess we look through it, if you can help me understand why you made certain changes as you went through. So this was the very first drawing. I remember, it might have been the Cartesian Diver that you mentioned this on. But you said that you didn't know exactly what to draw. That touches on what you said earlier, about feeling self-conscious about drawing, and just knowing the thinking.

Eileen (22:45):
Yeah. I think it was with this one, where I didn't know really what to draw. Because for the one with the water on Earth, I knew that the water was dripping down off of the wet wash cloth. I knew how to draw that. I knew that part of the reason why the water droplets were falling down was because of gravity, which is something I have learned about before.
But for the space one, other than knowing that there is not gravity in space, I wasn't really sure why the water droplets stayed together. I figured it might ... I still had them drawn close together in the magnifying glass, because I had the understanding about how the molecules being closer together represents a solid. So I knew that it looked kind of like a gel. But I feel like on this one, I just showed what I could see, or try to piece together what was happening.

Interviewer (23:44):
Okay, and that was intentional. If I look at the magnification for the right in space, you have them closer together, and then they're further apart on Earth. So that was, you were-

Eileen (23:57):
Yes, that was intentional.

Interviewer (23:59):
... spatial. Okay. Yeah, I thought that it was when I looked at it. Yeah, you were trying to indicate you were envisioning a difference in spatial arrangement.

Eileen (24:08):
Mm-hmm.

Interviewer (24:09):
Okay, awesome. With your next drawing, and unfortunately it has my little sticky notes on it. I thought that I took a picture without it, but I didn't. I only had a picture of your second one after I put sticky notes on.

Eileen (24:25):
With this one, I made sure, I think I added that showing the water on the wash cloth. Because even though the water was dripping off, there's still water on the wash cloth. Then I would say the big change that I added was, I showed charges. I drew the water molecule on both sides, with the positive hydrogen and the negative oxygen atoms. Then I made a gas, or a prediction about how maybe the wash cloth in space, because if something has a positive charge, since the water molecules have the negative charge, maybe that's why they're sticking to each other.

Interviewer (25:09):
Okay. I noticed you also here, and I'm assuming it's because I asked if your water molecule droplets were separated on your earlier one. You added more, and I think that's-

Eileen (25:18):
Yes. I added more because I didn't think that they were separated.

Interviewer (25:25):
Yeah, so that was in response to my question. Then actually adding the model or the depiction for the water molecules, this was the week that we did the two dimensional, and then did the gumdrop water molecules, and then-

Eileen (25:43):
[inaudible 00:25:43].

Interviewer (25:44):
I'm assuming that it was in response to the learning we did with the charging polarity, for that one.

Eileen (25:44):
Mm-hmm.

Interviewer (25:50):
Okay. Then your third one, I am not sure. Most people have changed the most from their first to their second. I'm not sure that when I looked at yours, I saw changes in the vocabulary. So adhesion?

Eileen (26:06):
Yeah. I think on this one, with the water in space, I talked about how there was force adhesion, making the water droplets stick onto the wash cloth. Which also came from us learning about that in class. I'm not sure exactly which activity that was though. Then for the wash cloth on Earth, I also am trying to see, I think I have something about attraction there.

Interviewer (26:35):
Yeah. This was where we did the penny, the water droplets on the penny. Then we did the maze, with the different materials. That would have been what we did that day. That's when I introduced the vocabulary, adhesion, and cohesion, to them. Which is reflected in your picture,
that you added that in. But it seems more that you used the words, but not necessarily images, to illustrate the new learning here. It was more a text update.

Then your last one, I think this might be the same as your last one. I did not notice any major ...
The last was when we revisited, looking at it again. You looked at your drawings, then you wrote your explanation.

Eileen (27:28):
Yes. I don't think I added anything to my last one, from the third.

Interviewer (27:33):
Okay. That's what, I didn't notice, but I wanted to make sure that I didn't misinterpret that. We looked at the changes over time. Like I said, after this last drawing. Then you wrote an explanation in your notebook. Can you speak to, in what ways do you think drawing your explanation affected what you wrote for an explanation in your notebook?

Eileen (27:57):
I think that drawing my explanation helped to show where certain things were happening. Or show my thinking visually. For me, I think it was also a lot easier to write out an explanation in my notebook, versus draw the explanation. So I think drawing pushed my thinking deeper. Because I do think with writing, that sometimes you're able to ... I think it's easier for me to put my thinking in words. But also, sometimes you're able to write around the question a little bit. You can't really do that when you're drawing.

Interviewer (28:39):
Okay, yeah. You can use, we call them buzzwords sometimes. When you're writing, but it doesn't necessarily reflect that you understand what's going on.

Eileen (28:50):
Mm-hmm.

Interviewer (28:51):
Okay, that's how I interpret what you were just saying. That's my interpretation. So in some ways you have touched on this a little bit. My question was, were there aspects of your understandings about water forces, that were helpful to draw?

Eileen (29:10):
Yes. I think showing, for the water in space, showing the molecules of the water close together was helpful to draw. Versus the ones that were further apart on Earth. Because I could have said that in my words, and I am pretty sure I did in my writing maybe. But I think it's easier to see it when it's drawn out.

Then I think with the pictures, it helps you to see, you can see the difference between the two a little easier. Because you're seeing them right next to each other.

Interviewer (29:48):
Okay. Then the flip side of that is, and you've touched on it a little bit, but I'll have you talk about it again. What about your understanding was easier to write than to draw?

Eileen (30:06):
I would say that it was easier, I guess just to write what I was thinking. I'm trying to think about the best way to word this. For talking about how the water on Earth was different from the water in space, I was able just to write down what I had written to the side, about the molecules being closer together. I was able to talk about gravity, and maybe attraction and adhesion. I can't remember exactly, and the charges. But I'm not sure how deep that understanding actually went, beyond what I wrote down. But yeah, I can't remember exactly what I wrote.

Interviewer (30:56):
That's fair. I was mostly getting at if you had to choose your ... So you have an understanding of it, and if you could choose to write part of it, which would you choose to write about, versus drawing?

Eileen (31:09):
I think I would choose to write maybe about the ... I'm trying to think.

Interviewer (31:25):
Another way to think about it was possibly, what was just difficult to draw, that you really felt like you just needed to write to fully show your understanding?

Eileen (31:36):
I think it was a little bit difficult to draw the water in space, just showing how it looks like a gel. Whereas the water looked more like a liquid on Earth. Because I did even add that in writing to my drawing, to show that difference.

Interviewer (31:53):
Okay, yeah. That's what I'm getting at. Things that you could think of, that it was difficult to really illustrate, that you wanted to explain. You needed your words to write. Versus-

Eileen (32:03):
Yeah, and maybe the reason behind why I drew some things, because I added that. But showing that the wash cloth has a positive charge, and why I thought it had a positive charge. Or just how you asked me earlier about, if I had intentionally made the little dots to show the water molecules closer together in one, versus further apart on the other one of Earth.

Interviewer (32:33):
Okay, yeah. Those were all, that's what I was hoping to pull from you for that, so awesome. Finally, we are thinking about these water forces, so I wanted us to go more broad and think about force and motion in general. Not just the water forces. In this last question, in what ways, if any, do you think your conceptual understanding about force and motion changed, developed, I guess you could use either one of those words, over this semester?
Eileen (33:08):
I do think it developed over the semester. I'm still not entirely sure if everything I drew on the right, for the space molecules, or not the space molecules, for the water molecules in space, is correct. Because I don't think that we fully went over it at the end of class, which might have been your point in not doing that.

But I think I learned more about attraction and adhesion. I hadn't really heard of ... Well, I'd heard of the term attraction obviously, with positive and negative charges. But I hadn't heard of force adhesion or cohesion before. Or if I had, it was really quick, and I forgot. So that was definitely something new that I found, and the activities made me see it in different ways. I really liked the penny activity, with the water droplets. I felt like that helped show what adhesion and cohesion are a lot.

Interviewer (34:11):
Yeah, my probing question was to ask you about any specific activities, so that's good to hear. Yes, you're right. I had intentionally designed this a certain way. So I needed one more week to do. If I could have, I might have done one more week with meeting making. But it's good to just hear your thinking, versus hearing something that I think parroted back to me, so there was a reason for that.

I think that we're done with the drawings, if you want to take this down. The last group of questions that I have are related to affects. So attitudes and beliefs. Now that you've finished the semester, how prepared do you feel for teaching the three strands of science? Life science, earth science, and physical science, in the elementary classroom?

Eileen (35:03):
I feel pretty prepared. I think I have more strategies to teach with, and I know more things about the pedagogy side of things. The different types of questioning, and drawing, and having them do science. I still think there is some science content knowledge that I don't necessarily have. But I think I know more places to get that knowledge now. I think that even if I had, I don't think you could ever know all the science content knowledge.

But even if I had learned all the science content knowledge, I would probably have to get a refresher anyway when I was teaching it. Because I definitely would forget something. But yeah.

Interviewer (35:53):
Yeah, so you answered my first and my second probe, and you gave some specific examples for the ways you feel prepared with the questioning, and some of the activities. Then you'd like more preparation. The content knowledge is something that you'd still like to know more about.

Eileen (36:08):
I know that our program also does give us a lot more content knowledge, being a STEM program. From what I've heard about my friends in other elementary ed programs, we take way more sciences classes than they have. Especially with the physics class. But I still feel it would be good to have more content knowledge for science.

Interviewer (36:30):
I'm well into my, as a practicing scientist, I always feel like I need more. So it's, everyone always can benefit from more content knowledge. Can you say whether your feelings of preparation differ based on the science strand? Does it differ based on whether it's physical, life, or earth?

Eileen (36:53):
Probably, I do still think that I'm a little more confident in life or earth science, over physical science. Yeah, I would say that.

Interviewer (37:05):
Do you know what makes you feel that way?

Eileen (37:10):
I think it's because, well I definitely remember spending more time on those strands of science when I was growing up. So I have more knowledge from my middle and high school experiences with that. Then physical science, I think there's some that I feel more confident with. Talking about mass and volume, that would be a physical science thing that I feel more confident with. But some other parts of physics, I can memorize what the textbook says is why it's happening, but I still don't really understand why that's the case.

Interviewer (37:50):
Okay. Yeah, that's good. So you don't have a model, or a way of having an analogy to explain-

Eileen (37:57):
Yeah.

Interviewer (37:58):
You can say the words. You could do Newton's first law. But knowing what that means might-

Eileen (38:03):
Yeah, because I think too, with the life and earth sciences, of course there's reasons why everything happens. But a lot of that science is more of what does happen, versus I feel like the physical science gets into a lot of why things happen. So that might be why it's a little harder too, for me.

Interviewer (38:23):
Okay. Yeah, those are all helpful ways to understand why you feel the way you do. Do you envision incorporating drawing as a strategy in your own teaching one day?

Eileen (38:36):
Yes, I do. I don't think I would have before this class, to be honest. For this class, I really hated drawing, for science purposes. But one thing that I realized when I was doing the cloud in the bottle with the students is, having them draw what they see happening while the experiment was going on helped to focus their attention so much. It helped them pay attention, because it gave
them something to do. They found it a little more exciting too, than just having to write out their thoughts. We did have them write later on. But it was more exciting in the moment.

I have realized how much it can help you with understanding student thinking. Seeing on that level, like I said earlier, about how deep they understand a topic.

Interviewer (39:19):
Okay. Yeah, and you gave, I was going to ask you why you feel that way. You answered that, and also thinking about how you would incorporate them. So those answer both of my probing questions, which is good. Then the last one, it gets into an affect or a feeling. You've answered this, but I'm just going to ask it again. How do you feel about drawing for your own learning this semester? As you reflect on this semester, how do you feel about drawing?

Eileen (39:48):
I feel better about it. I feel like now, drawing can be more helpful for my learning. I still don't love drawing, myself. It still makes me a little self conscious, and definitely when we do get provided with graphic organizers, to help scaffold our drawing. But I think now, I can see that there's a benefit to helping me learn when I draw. Whereas before, not only did I not really like drawing, but I didn't really see the point in why we were drawing for school. So now I feel like it does help me learn, and also see what I understand or don't understand a little more.

Interviewer (40:28):
Okay. Yeah, and you're good at answering my probing questions. You did already talk about challenging, because you didn't really like drawing, or see the point of it. Then being worried about what you were drawing. So you answered some of the challenging things with that. Then you talked about how it was beneficial to you. Then you even answered how your attitude changed over the semester, so I don't have to break those down. You hit on all of those things. Those are all of my questions. Anything that you want to add, that comes to mind, that maybe I didn't touch on with the drawings, that you think would be useful to share? Or useful to share about your semester in general?

Eileen (41:11):
I don't think so.

Interviewer (41:14):
Okay. Well with that, I'm going to stop the recording.
Joan's Interview Transcript

Interviewer (00:10):
So really quickly, Joan, I have to be careful not to call you the pseudonym. I keep thinking it. That's what stuck in my mind now, because if I look at your guys' data. So I just wanted to verify that you've given me consent to audio tape and record this interview.

Joan (00:25):
Yes, I have.

Interviewer (00:26):
Awesome. So thank you very much for helping out with this. So our first question is kind of looking at what we call pedagogical content knowledge focused questions. So my first question is for you to say something about how do you think students learn best about science?

Joan (00:46):
I think making observations and having them come to their own conclusions is really helpful. And then having that backed up, later explained after they come to their own conclusions is really helpful. Because I know in classes, it was helpful to think through it on my own first and then have it explained after.

Interviewer (01:06):
Okay. Were there any ways that your ideas about teaching science changed over this semester?

Joan (01:17):
Definitely the drawing aspect. I know that was a big focus throughout our classes, but honestly, when I was in high school, my teachers would ask me to do it and I would hate it because it was kind of boring. But I can see it as being helpful now because we did it so much in our class. I was able to think through my stuff more and think through my thinking more by drawing and because we kept going back to the same drawing, it was really helpful rather than starting a new drawing every time.

Interviewer (01:49):
Okay. That's good to know. So this kind of leads into that a little bit and you've touched on it a little bit. So what are some ways that you think drawing might be useful as a science teaching strategy to facilitate student learning?

Joan (02:03):
I think it definitely helps students talk through their thinking if they don't know the words for it, just in that kind of way. Because sometimes it's harder to say something and it's easier to draw it out and it creates like a visual that is easier seen than said in words.

Interviewer (02:25):
Okay. What do you think students might have difficulty with regarding drawing in school?
Joan (02:31):
I know younger students get frustrated when you ask them to draw something that's more complex. So I feel like that could be a big difficulty in letting students know it's okay if your drawing's not perfect. But some students get really frustrated if they mess things up or do it wrong.

Joan (02:47):
And then maybe also letting students know that their picture's not going to be perfect the first time. Because I know we kept working on our space picture throughout the whole semester and students might struggle with adding to it maybe a little bit, but yeah.

Interviewer (03:04):
Okay. That sounds good. And so the thinking about how you're instructing students, one of the things that informs me, excuse me, are your lesson plans from the semester. So I wanted to look at those first. So if you could pull up, share the redirect week one, that would've been the first link that I put in the chat window. If you can pull that up and share it.

Joan (03:30):
Let me see.

Interviewer (03:31):
I'm going to pull up my window so I can look at it while you're walking through it. Awesome. Very good. Yeah, I see it. Okay. So what I'd like for you to do is for you to walk through, I know that you haven't seen it in a while, so you might want to scroll through and take a look at it, but I want you to look through it. I'd like for you to share some of your thought processes, like what resources or learning experiences influence what you decided with Molly to include in this lesson plan.

Joan (04:04):
Well, sorry.

Interviewer (04:05):
That's fine. Take your time. Yeah. I debated whether I should send these ahead of time, but I thought it would be best just to kind of look at them together. So I knew everyone was spending the same amount of time looking at them as they commented. And so this first one was when you were doing that Page Keely probe.

Joan (04:25):
Yeah. I guess when making this lesson, we had been taught a lot throughout the whole year about inquiry based learning and questioning and having students come to their own conclusions. And that was kind of like the whole point of this lesson, was to have students use their own thinking to explain a phenomenon. So we wanted to... sorry.
No, no don't say sorry. It is fine to, for there to be quiet pauses where you look at things and you think about what you guys had on there.

Joan (05:02):
I guess. Okay. This first part, we just wanted students to get into the mindset of thinking about cells, because that was the purpose of our worksheet, was getting them to think about cells. So we asked if they knew what a cell was just to make sure that knowledge was there. But then we didn't correct them in any way, we just had them leave their own discussion.

Joan (05:23):
And then moving into the explore phase, like we gave them the worksheet, but then prep the worksheet, explained to students there's no right or wrong idea on the worksheet so that they didn't feel pressured to pick one or stressed about not knowing the right answer. And then we allowed them to write their ideas on their own. They did it completely independently. So it was truly their own thinking. And then after that, at the very end we had them... I don't [inaudible 00:05:58] sorry.

Joan (06:06):
I don't know if this is what we ended up doing actually, like the dot and then the dot graph. But we had a discussion around the three ideas and just had them really be that discussion about, there were three ideas on the worksheet and they had to choose from one of them and we had each of them explain like, why did you choose this one versus the other one? But not influencing their answers in any way. But we didn't do the dot graph.

Interviewer (06:33):
Okay. Yeah, sometimes your lesson plans you don't always end up doing, because you don't know what the time that you have. Thinking about that middle section with the explore when the students were, could you say more? I think sounds like they were just writing and then talking about their explanations there.

Joan (06:53):
Yeah.

Interviewer (06:54):
Okay. And was there any reasons why you stuck to just the writing? Was it mainly based on the way the pro was set up? Do you remember?

Joan (07:06):
Yeah, it was a fifth grade class and a lot of stuff that they do in that class is writing based. So we wanted to stay with what they were doing in class.

Interviewer (07:15):
Okay. Yeah. So you were following the consistency of what the teacher was doing. Oh, awesome.
Joan (07:20):
Yeah.

Interviewer (07:20):
So let's do the same thing with your second lesson plan, if you can pull that one up. And you can spend a few minutes taking a look at that. That was your discrepant event with the line, like the lava.

Joan (07:33):
Yes. Yeah. Okay. Yeah. I remember this one.

Interviewer (07:57):
Yeah. Yeah. It's hard when we're doing this a little bit delayed, but I wanted to make sure we were talking about this after we had grades in. So yeah. Okay. So go ahead, talk about just resources or thoughts that influenced how you set this all up.

Joan (08:13):
I guess, similar to the last lesson in the beginning, we wanted to make sure that they had the tools necessary to do the lesson well, if that makes sense. So we went over how to make an observation and that was discussion. I asked them like, "What is an observation? How do you make an observation?" And then they answered. And then I'd gather them a little bit while I was giving lesson if they didn't give everything that I wanted to hear from them.

Joan (08:45):
But yeah, that is how we started the lesson. And then I know for me personally at least, I'm more engaged in a lesson if like I'm actually able to do the science. So it was blobs in a bottle and I had these little ice bottles, like sparkling drink and I took the labels off and I gave them all like groups of three or four, each got one bottle so they were able to do their own experiments sort of in groups and see it closer, to help engage them and get them more invested in it.

Joan (09:20):
And then they had worksheets that we gave them for the explore phase that allowed them to draw their observations, like what we were doing in class. That came from what we were doing in class and I wanted to apply it to the lesson. And the worksheet had a before, during and after section so that they could see the change drawn out. And when we gave them the worksheets, or when I gave them the worksheets, I asked them to make their drawings as detailed as they could, add color if they wanted to and label everything. And prompting them with that, they did a lot of that, which was nice to see. And at the bottom of the worksheet, there were just lines for them to write if they felt the need to. And they all wrote like a little sentence or two to explain their observations, which was cool.

Joan (10:16):
And then we all had them do their own little mini experiment, sort of. So like I filled the bottles with the water and the oil and then they dropped in the Alka-Seltzer. But then as I did every step
in front of them, I asked them like, "What do you see is happening right now?" Because when you put the water and the oil together, they don't mix. So I had them predict what was going to happen so that they could have their own thinking beforehand, and then poured in the water on... I don't know what I did first. But I poured the second liquid in and then had them discuss what actually happened. And we did that every time we added a new element to the bottle, just to get their talking and discussion going.

Joan (10:58):
And then they were split into groups. So when we dropped the Alka-Seltzer tablets in the bottles, I told them like, talk about what's happening with your group. And so they talked with their group, what they saw happening. And then we had a whole group discussion after that, just to kind of get them talking about what they were seeing. And yeah. So then that was kind of this little discussion part.

Joan (11:31):
And then we wanted them to share their drawings a little bit if they felt like they wanted to. And then at the very end, just for our explain phase, we asked them to think of other questions that we could explore. Like this is this. And I kind of changed this in the lesson. So I asked them, I asked them what other areas we could explore and had them come up with the questions. And then I gave them some questions. And then we talked around what that would look like to get their thinking, going a little bit more. And then that was pretty much it.

Interviewer (12:08):
That sounds good. Did you say the students, you let them share, do you remember anything about the students' engagement? What did you notice about the students' drawings themselves?

Joan (12:24):
They were all really detailed. So I remember, I have them still [inaudible 00:12:29].

Interviewer (12:29):
Oh, nice.

Joan (12:29):
I don't know how to get them. Okay. There's carbonation that goes, or air bubbles, that are in the bottles when you put the Alka-Seltzer in and they were very detailed and drawing out little bubbles and labeling the colors. And don't know how to describe it, but they were very detailed because I asked them to be very detailed if that makes sense.

Interviewer (12:57):
You know how showed you some of the foundational images, did you do any drawing, scaffolding of the drawing instruction or you let them decide what they were going to include in terms of like symbols or information?

Joan (13:13):
I kind of just let them do it on their own, because they've drawn pictures similar to that in class before. But then I also told them to draw arrows to label stuff, that is the only...

Interviewer (13:25):
The only explicit visual literacy thing that you did. And did you do any scaffolding, like giving them words to use to label or they've just labeled based on what they wanted to call things.

Joan (13:41):
They labeled based on what they wanted to call things.

Interviewer (13:43):
Okay. Yeah. Awesome. And I think I remember, I can go back and look, the worksheet or the graphic organizer you gave them, did you put a bottle on there for them? And why did you decide to make that decision to put that on there for them?

Joan (14:07):
I guess it's less important for older students, but sometimes students will get stuck on just drawing the bottle and get frustrated, but that was the least important. It was the one thing that stayed the same across all of the experiments. So I wanted to take away drawing that factor and just save time by letting them draw inside.

Interviewer (14:24):
Okay. Yeah, I thought I remembered your organizer when I looked through it, had that on there, so okay. I think that is good. Anything else you wanted to add about the lesson plans that you can remember?

Joan (14:38):
Not that I can think of. Just discussion, lots of it.

Interviewer (14:45):
Okay. Okay, so yes, I'm looking because I have different questions depending on which subgroup you were in, you were in my drawing subgroup. So what do you think, if anything, and you can stop sharing if you want to, you don't have to have it on there. So what do you think, if anything, you learned about science teaching and learning by us focusing on drawing this semester? So there's anything particular that you learned about teaching science or that you learned about science because of our focus on drawing in your subgroup?

Joan (15:21):
I mean, I guess because we kept going back to the same drawing, which I've never done before, I was able to see how my thinking changed throughout the semester and how my drawing changed and got better throughout the semester. And in teaching, if I did a similar thing with my students, I could see how their drawings changed throughout the semester kind of thing.

Interviewer (15:44):
Okay, yeah. So I might have to come back to that. And are there any ways that our focus on drawing and science influenced, and I think you kind of talked about that just now being able to use drawing to see their progression, but has there been any way that our focus on drawing during the semester influenced your knowledge about students' thinking?

Joan (16:13):
Oh, I guess when I drew my first drawing, I'm going to pull up really quickly.

Interviewer (16:18):
You can pull it up if you want to. We're going to look at those in a minute. So yeah.

Joan (16:22):
My first drawing, to show the squeezing extra two arrows in, and then you left feedback. So you were like, are you really squeezing in to get the water out or is it a more wringing thing? And so then I changed my drawing to be a more wringing motion. So being more detailed in drawing. So when teaching and when asking kids to make observations, being very specific in what I want from them kind of, and working with them to make their drawings more accurate over time.

Interviewer (16:55):
Okay. Sounds good. Glad to know my feedback was useful for encouraging [inaudible 00:17:02]

Joan (17:02):
It was.

Interviewer (17:04):
And so that's actually what I want to look at now, if you can share your drawing sequence. And you can do the slideshow probably would make it the easiest for us to both see it at the same time. I want to start by looking at your final drawing. So it will be the very last one. Okay.

Interviewer (17:26):
So in looking at your drawing, the very last one, I can look at it and make an interpretation, but if you could talk me through what you were illustrating and you might want to take a few minutes to look, because I know it's been a while since you've looked at that as well. But just think about the different things you've illustrated and maybe what you're trying to show and why you decided to put that on there. Because as I look through it and interpret it, you make sure that I'm interpreting it correctly.

Joan (17:58):
So I guess the first drawing was the water on Earth. And one thing I'm just noticing right now is you kept asking us every week to add something to our drawing. So I just kept trying to draw something every week, even if I didn't know what to draw exactly. But I think that helped my drawing become better. But in the drawing, I was trying to explain what liquids are on Earth. And so they'd take the shape of whatever they're in. Because we had talked about that in class. So then the water takes the form of the washcloth, that was what I was trying to explain there.
Joan (18:43):
And then the arrows I drew around the washcloth, like here was just the way that the squeezing force acted on the washcloth, which is the same in space. But then for water on Earth, the water like falls the ground because of gravity. And to be specific, I drew what a water molecule looks like right there.

Joan (19:08):
So that's explaining why the water falls. And then over here I was getting into, we had talked about adhesion and cohesion. I don't remember which is which, but about the charges of water. And so I have no idea what I was... I think I was trying to draw like there's a lot of oxygen in Earth and so oxygen might have a negative charge. So water's not affected as much. I don't know.

Joan (19:36):
But then moving over to my space drawing, I noted that there's no gravity in space, so the water's not going to fall down like it falls in this image right here. Yeah. And so then I explained the water, this is the washcloth. And then outside the washcloth is another little squiggly line, which is the water around the washcloth. And I said, it stayed together because of adhesion. The charges kept the water together. And there's no gravity, so it doesn't fall. This little guy that I was drawing. Because I noticed in the video, the water kind of stuck to the astronauts hands. I was like maybe people are slightly charged in a positive way. So the water like sticks to the person, like the penny kind of thing. And yeah, water has a more negative charge, so it sticks to the positive. Yeah. And then that's just kind of what I explained in more detail here.

Interviewer (20:45):
Okay. And looking at your washcloth between Earth, I'm looking really careful there. So it looks like the washcloth on Earth, are the dark spots supposed to be, were you trying to illustrate water molecules there versus-

Joan (21:02):
Yeah, just taking up the space of the washcloth.

Interviewer (21:06):
Okay. I thought that was what you were drawing there.

Joan (21:09):
Yeah.

Interviewer (21:11):
Thanks, that's helpful because I can go back as I'm looking through it and thinking about what you conceptually put on there. It helps me to hear you talk about it, to make sure that I'm interpreting the image correctly. But one thing I'd like to do now is to step through. So if you went to your first slide, I want you to just maybe look at how you added on each time and maybe explain why you made certain changes. If you remember why you made certain changes over
time, your second drawing's going to have my little stickies on it, hopefully you can see most of it.

Joan (21:49):
So this is my first drawing and you can see the squeeze to push the water out was just on the side. And then there was no squeeze or the squeezes on the side in this one too. And that was pretty much it for that one.

Interviewer (22:07):
And you added the little magnification. So when we did the Cartesian diver, that was prior to me showing you some foundational images. So on that first drawing the magnification, is that because we had covered that as where you did the expanded view of the actual water molecules? Do you remember if you were using what we had covered in class?

Joan (22:35):
Yeah, I was.

Interviewer (22:36):
Okay.

Joan (22:39):
Okay. Yeah. And then-

Interviewer (22:40):
My little stickies all over.

Joan (22:42):
It's okay.

Interviewer (22:43):
I thought I had taken an image of it without it, but when I went through my records, either I saved it in a place that I don't remember saving it because I was so busy, or I wanted it to have the stickies on it.

Joan (22:59):
Okay, this one, the squeezing motion, I specified the direction that it goes because of the sticky that you put right here. I was like, "It's not horizontal." So then I tried to illustrate that with my arrows. And I think in that class we had talked about what a water molecule looks like and gone into the positive and negative charges and then I drew what a molecule looks like.

Joan (23:27):
Yeah. And then I think I got really into the charges. So then that is what was happening down here. And I was trying to illustrate that and illustrate what we get talked about in class. So I was
saying like, maybe a person is more positively charged and water's negatively charged. So then it is attracted to the person in a way. And then that is kind of what I explained more here with the hand.

Interviewer (23:53):
And you can't see it, but you'd had the earth over there also. So that was the one, so our work with the modeling, with the molecules, it started you thinking about charges?

Joan (24:05):
Yes. Is that the same picture or?

Interviewer (24:10):
No, no, so on this one, the only thing that I noticed that you added differently was at the bottom was the penny. And then I didn't notice anything different between your third and your final drawing.

Joan (24:26):
Oh. Okay.

Interviewer (24:28):
But I think it's because we did the water, the drops on the penny and the maze, the third drawing, that was that. And I think the fourth was just rewatching the video. So I'll get you to maybe say a little bit about that, but yes, just so you're fine. I did not notice anything different between your third and your final drawing.

Joan (24:51):
Interesting. I guess I just do the pinning to amend that.

Interviewer (24:56):
Yeah. So the second one, yeah. Yeah.

Joan (25:02):
Okay.

Interviewer (25:03):
Looks like you just observed that the behavior of the water looked like the water on the penny was what I noticed on this one.

Joan (25:10):
Yeah, yeah.

Interviewer (25:19):
So it looks like the charge thing was very impactful for adding on.
Joan (25:25):
Yeah. I don't know, I thought we had talked about it in class. So then in my head I was like, "This is really important." So then I wanted to reflect that in my drawing somehow. I don't really know how, but I tried to.

Interviewer (25:37):
Yeah. And I'm looking to see if you added any vocabulary on here for adhesion and cohesion. I'll have to look back at your drawing. That's the hard thing about doing it electronically, is it's you don't see. I have the hard copy that I can look at for your final one, but I see water molecule, but I'm not sure that I see the [inaudible 00:26:01] on the final one.

Joan (26:07):
Cohesion and [inaudible 00:26:09] other hand, yeah.

Interviewer (26:10):
Okay. You have it down there.

Joan (26:12):
And then adhesion is...

Interviewer (26:16):
Oh yeah. And you used also the cohesion down on the penny, you pointed to that also. So you did add that in on your third drawing. Okay. All right. That looks good. I think I need to check, make sure I'm not missing anything. So that's helps, like looking at the drawings. And so thinking about after you guys did your final drawing, you wrote your explanation in your notebook and you posted it on Padlet. And I'm wondering if you can remember or think of any ways that drawing your explanation affected what you ended up writing for your explanation. Was there any way the drawings affected that that you remember?

Joan (27:13):
I guess I used the drawing as a guide to make my explanation. And so if I didn't have this drawing in front of me to make my explanation, I think I would've been a little bit lost. And I think my explanation wouldn't have been as... I don't know how detailed my explanation was, honestly. But I would hope that it was detailed because I had so much drawn on this paper versus I think if we had not drawn, I would've probably lost some of the knowledge that's in this picture. So it would not have been reflected in my explanation as much.

Interviewer (27:45):
Okay. Yeah. And if you can remember, this is a hard thing about having to do this after the fact, were there aspects of your understanding about water forces, that it was helpful to draw them that you think were particularly helpful to draw?

Joan (28:05):
I mean, I think the adhesion and cohesion, I had not heard about that. I don't know if I learned about it in elementary school, but those were new words for me. And so being able to draw that and then refer back to them was definitely helpful.

Interviewer (28:17):
Okay.

Joan (28:19):
Yeah, with the penny.

Interviewer (28:20):
Okay. And can you remember anything that, or as you think about it, even now, that it's easier to write about the phenomenon, your understanding about it versus drawing it? Are there aspects that you would prefer to write?

Joan (28:40):
I feel like the squeezing part was a little bit hard to illustrate because it's like a wringing and not like a push. So I think that is easier to write because you can just say like you wring out a wash cloth, but harder to draw.

Interviewer (28:55):
Harder to draw, come up with a model for drawing that. That sounds good. And so thinking about all of this, both working with this water and then anything else that we did. So what ways, if any, do you think your conceptual understanding just about force and motion, not necessarily water forces, just force and motion in general changed or developed over this semester? Are there any new understandings or different understandings that you have about force and motion in general that changed over the semester?

Joan (29:37):
Honestly, not that I can think of, but I also went into this class, like I took the elementary physics class last year, second semester. So then when we did the assessments that we were doing in class, I recognized a lot of the drawings because I had done them the two semesters prior. So the knowledge was still kind of fresh, so I can't think of anything that changed [inaudible 00:30:00]

Interviewer (29:59):
So you did that your sophomore year, then?

Joan (30:03):
Yeah. Sophomore year, second semester.

Interviewer (30:06):
Could you say more about that class? Did they draw in that class?

Joan (30:10):
Yeah, yes we did. It was on Zoom and we were given a workbook that we had to buy. And we just worked through each section of the workbook, every class and drew our thinking kind of. So we worked a lot with the trains on a track, so like there's no gravity. And so we had to draw arrows to show the direction of force and then that kind of stuff. So yes, it was a lot of drawing. So then when I saw forces on the assessment that we did, I recognized it because we had done that, or I had done that.

Interviewer (30:51):
Okay. Does everybody take that course?

Joan (30:54):
Yeah. Yes. Or they should, yeah.

Interviewer (30:58):
Okay. I thought that they did. So there's not different physics courses that you can take. It's the one that all of the education majors, if they're going to take one, they would end up in that course.

Joan (31:11):
Yes. Although I know my professor at the beginning of the semester said he was teaching some of his courses differently. I don't know. I don't remember him saying that.

Interviewer (31:22):
If you can email me, it would be really helpful, I can probably look up the number, but the workbook that you used, that would be interesting I think for me to take a look at.

Joan (31:33):
Yeah. No, I can do that.

Interviewer (31:38):
And were there any activities in particular then that reinforced, I know you said you recognized a lot of it on those with the at last assessments that we were doing. Were there any activities that we did that reminded you of some of the things that you had done previously or reinforced things that you had already learned?

Joan (32:00):
Regarding forces, when we took the balls and rolled them down the ramp, we had talked about that a little bit in that physics class. So that was just kind of reinforcing my knowledge. Because we talked a lot about friction and gravity and there was like a whole unit on forces and how they affect motion. So when we talked about pushing things or rolling things down the ramp, that's when I was reminded of.
Okay. Of what you'd done previously. Yeah. But definitely if you'll email me the workbook, that would be useful. Because I'd like to take a look at that. So the final group of questions. So now that you've finished the semester, how prepared do you feel for teaching the three strands of science? So life science, Earth science and physical science in the elementary classroom.

Joan (32:50):
I feel good about it. I think definitely this whole year, I've learned more about how science is discussion and observation and having the students do the thinking based rather than me just lecturing, "This is why this happens." So I think prior to this, just this whole school year, I was a little bit worried about science in all areas, because I was like, I don't know, every single scientific phenomenon that is out there. But then after this year I realized that's okay. And I can learn with my students and that kind of stuff. And have them make observations and then work off of their thinking to create future lessons, yeah.

Interviewer (33:33):
So are there some particular ways that you can think of, like a specific example where you feel well prepared?

Joan (33:43):
I guess when doing the second redirect lesson with the blobs in a bottle in comparison to like other science lessons that I'd done in the past, I know I was really nervous for like any other lesson I've ever done. But for blobs in a bottle, I was not, because I knew going into it, it was purely observational. There wasn't a lot of stress for me because I was just going to ask them about their thinking. And I had a little bit of background knowledge prepping for the lessons. So I felt good answering questions that they had. But that I just felt really comfortable having them sit and make their observations and have discussions and then prompting them to move further in their thinking and that kind of stuff.

Interviewer (34:27):
Nice. Okay. So what are some ways that you feel like you need more preparation?

Joan (34:39):
Really, I don't know. Yeah. I guess just more practice, but that is just going to come with time, so.

Interviewer (34:48):
Yeah. I would agree. And do you have different feelings of preparation based on the science strand? Do you feel say more prepared to teach life earth and physical sciences? Does your preparation vary based on the strand?

Joan (35:05):
I think I feel more prepared to teach physical sciences because the experiments that you can do with that are sometimes more straightforward. Like forces of motion you could have them pushing cars and that kind of stuff. I guess Earth science is a little bit more stressful in my head
thinking just because I don't know as well how to find representations for that. Like the blobs in the bottle experiment, but then I know like I can Google and there's stuff out there that I can find. And same with life sciences. So I guess I feel more prepared for physical science, less prepared for like life. Oh my gosh. And the other one, but...

Interviewer (35:52):
Yeah, no, yeah.

Joan (35:53):
Yeah. But there's a very small difference in feeling prepared for those, like just slightly more prepared.

Interviewer (36:02):
So it sounds like what you're thinking, you could come up with examples for ways to have hands on material, if I'm hearing you correctly, or a visual, some type of representation that you could incorporate. And you're not sure exactly how to do that necessarily with the Earth and the life sometimes.

Joan (36:19):
Yeah. Well in a fun way, because sometimes Earth like "Go outside and make..." Well, I don't know, but yeah.

Interviewer (36:25):
Yeah, no, that's fine. Yeah. That's a good thing to share. And do you envision incorporating drawing to learn and as a strategy in your own teaching one day?

Joan (36:39):
Definitely, yeah.

Interviewer (36:41):
Can you say a little bit more? Like why would you want to do that?

Joan (36:46):
I think it just helps, especially with younger students just draw out their thinking. Because articulating stuff and writing stuff down is sometimes really hard. And so just being able to draw it and not have to think like, 'How am I going to write this in a way that this person's going to understand?' Is really beneficial. And I think it would definitely help me see my students' thinking past just their words. Because sometimes words are hard.

Interviewer (37:11):
Yeah. Yeah. Do you have some specific things that, I know you talked about having them draw their thinking, so some specific places in your lessons that you could see yourself incorporating them? Maybe thinking in terms of purposes, like what purpose would you use them for?
Joan (37:32):
I guess like the blobs in a bottle having them draw before, during and after. So if we're ever working on an experiment where they're making observations, having them draw something before, during and after. Or if we're doing a, I don't know if there's a unit on plants, well, there has to be a unit on plants at some point in time, but if I'm ever doing something with students where we're growing our own plants, having them keep a journal and draw and describe the progress of their plant over time. But making sure with every drawing like that, it's all over time so that they can see changing growth and that kind of stuff.

Interviewer (38:06):
Okay. So it sounds like that freed them to really monitor their own learning. You talked about that earlier, how your drawing helped you see how your thinking changed over the course of the semester. And so that kind of leads into my last question for you, is how do you feel that drawing helped your learning this semester? Your own drawing.

Joan (38:38):
I mean, I think it just helped me put what I was thinking onto paper. Something that I couldn't say in words, I could put on paper, if that makes sense. I don't know.

Interviewer (38:48):
Yeah. No, it does make sense. Yeah. What are some things that you found challenging about the drawing?

Joan (38:53):
I don't know. Sometimes when you asked us to add more, obviously between my final... these drawings, I started adding less, so it was hard to keep adding stuff to it. And I guess also, okay, if I realized that my thinking was wrong in the past, having to erase it and like redo it, would've been hard. And the only example of that with my drawings was the squeezing. And that I just had to erase an arrow and then redraw it. But if I had done something that I disagreed with on my first drawing and it was really big, it would've been harder to correct in the future.

Interviewer (39:37):
Okay. That's a good observation. And I had a question on here about it being beneficial, but I think that you've already touched on that a little bit, about discussing that it helped you be able to put your thinking down and that it helped you see your progression of your changes in your understanding over time. Is there anything else that you can think of that you didn't touch on that you thought the drawings were beneficial to you in some way?

Joan (40:10):
Oh, I guess also when making my explanation, it was so much easier to look at a drawing than to look at pages and pages of notes. Because if you had asked me to make an explanation, if we had just handwritten notes for the whole semester I would've probably been very overwhelmed and not looked at everything. But the picture put everything in a nice spot altogether that I could look at and recognize immediately, what it meant.
Interviewer (40:39):
That's good to hear. And then I think you touched on a little bit, but I wanted to see if your attitude may have changed about drawing over the semester.

Joan (40:50):
Yeah, no, I think I have a better appreciation for it than I did before the semester. And understand more why drawing is useful in classrooms, just because it helps students put their thinking on paper. That's my understanding of it.

Interviewer (41:05):
Do you remember what you thought the first time I asked you to draw? I know the first time I asked you to draw was the Cartesian diver. So do you remember your reaction when they first asked you to draw by chance?

Joan (41:19):
I remember I didn't understand how that worked. And so when you asked us to draw it, there was a lot of like, I don't know how to draw this and kind of like, I don't know how to explain this on paper, if I don't understand the phenomenon that's happening. So then I just kind of drew what I thought. But then I know if that were a lesson I were doing in my classroom, or in someone else's classroom, I was a student, we would keep adding to the drawing and my understanding would further. But definitely some anxiety because I was like, "I don't know how to draw this or explain this," but yeah.

Interviewer (41:53):
And do you think that changed as you drew? Like for example, if I asked you to draw now, would you feel the same way you did the first time that I asked you to draw the Cartesian diver?

Joan (42:05):
I think the first time you asking me to draw or explain any kind of phenomenon, there's going to be some kind of anxiety, because I'm not going to know about the phenomenon. But then adding to that drawing, as I added to the washcloth drawing, my anxiety went away and I was fine because I knew I was just drawing my thinking.

Joan (42:26):
So I think the first initial drawing will always be a little bit stressful because I won't know how to really put my thinking down. But then once I add to it in the future, there's less anxiety.

Interviewer (42:34):
Okay. That sounds good. And I think that's it in terms of my questions. I think I covered everything that I wanted to talk about. Anything that you can think of that you'd want to add that maybe we touched on and you can think of additional things you want to say or just anything in general you might want to add?

Joan (43:01):
I guess nothing. Okay, with the pictures I think it's really helpful if they're explained after the fact. Because still looking at this, I know like I drew what I thought about the washcloth, but then I still don't completely understand why the water didn't... I didn't understand completely completely why the water did what it did. So I guess the drawings were helpful, but then they would also be helpful with an explanation in the end, if that makes sense.

Interviewer (43:34):
Yes. Yeah. So if we'd done an extra sense making, yeah. I guess that would've messed up my research a little bit. Yeah. That would be good. Well if that's it, I'm going to stop the recording really quickly.
Reece’s Interview Transcript

Interviewer (00:09):
Reece, just want to verify the start of this that you consent to be recorded for the purposes of my research.

Reece (00:17):
Yes. I consent to be recorded.

Interviewer (00:19):
Thanks. We'll get started. The first questions I'm going to ask are oriented toward what we call pedagogical content knowledge so your knowledge about teaching science. My first question is how do you think students learn best about science?

Reece (00:36):
I think students learn best through hands on experimenting and being able to explore science and then coming up with their own ideas and then having the teacher refine them over time. Doing a series of lessons that are hands on and then adding in the science content knowledge to help refine their thinking.

Interviewer (00:57):
Thanks. And so thinking about that, in what ways do you think your ideas about teaching science may have changed over this semester? Do you think that they were different at the beginning versus the end.

Reece (01:13):
Yes. They were very different at the beginning versus the end. Initially how I've always experience science teaching was that the teacher would just lecture about a topic and we really didn't get to see many models or hands on. What comes to my mind is just freshman year biology. All my teacher would do was send us Google slides and be like, "Okay, you have to memorize all this information." And it really didn't make sense because it was just all written and there wasn't really any diagrams or hands on experimenting. And I think that over the course of the semester, my ideas have changed because I realized that's not necessarily a wrong way to teach science, but it's probably not the best way because our students really should have visual models and should be able to actually experience the science firsthand instead of just have written out notes or just written out information.

Interviewer (02:09):
Awesome. And then thinking about, you were talking about hands on, what are some ways that you think drawing might be useful as a science teaching strategy to facilitate student learning?

Reece (02:21):
I think drawing is really useful as a strategy to facilitate student learning, especially for students who may have trouble with writing out explanations. I know for our first redirect week lesson,
we have one student and he's on the autism spectrum and he has trouble writing out complete senses. He needs help from his aid, but he did, or no, this is our second redirect week lesson, but he did a fantastic job of just drawing the explanation because we did a canned rocket. He was able to draw the forces and the arrows and he was so excited because he was able to communicate his ideas to the class.

Interviewer (02:58):
That's a nice example. That's pretty cool to hear. And do you think that there's certain things that students might have difficulty with regarding drawing and science?

Reece (03:10):
Probably some of the forced diagrams and just the specific like molecules and stuff, but I think what you did and modeled them probably would help students understand. I know for me I'm not the most artistic person, so I have trouble drawing. But I think it's a really cool way for students to communicate their ideas. And as long as you provide some scaffolding in the beginning, it makes it an easier process.

Interviewer (03:33):
Thanks. And so you've actually already touched on a little bit. I wanted to look at your actual fill work lesson plans. If you can pull up the first one and you might want to take a few minutes to kind of scroll through just to reorient, because I know that was back in February that you did that one. But just kind of look through it and then what I want to talk about is as you look through the plan, I want you to share what resources or learning experiences influence the activities and assessments that you included in it. You can take a few minutes just to look through it. As I told Jordan in the earlier interview, I thought about sending them out early, but I wanted to make sure everyone had the same time period that they were looking at them so that the responses would be similar. Some of you may look at it and some may not, and then the responses might be more robust and for different people. And this first one was your page Kelly probe?

Reece (04:50):
That's right. A while ago.

Interviewer (05:17):
Yeah. That's a trying to make sure that we were done with the grading before I did this interview that I knew that there was the lag of time was going to make it tough. Go ahead and you can just walk me through the resources or activities and things that influence how you decided to set it up or what you decided to include.

Reece (05:45):
Let's see. For our icebreaker, this kind of ties into our math methods course, but we were doing different types of graphs that we wanted student to see their visual thinking. We did a little, I think it's a histogram or I don't know, one of the graphs and we had them put an X next to early bird or night owl, part of our lesson plan we had the probe. And because we talked about in class, how we did the probe and how like there wasn't a correct answer. We made sure to tell students that there wasn't no correct answer and more geared the activity towards science is about sharing
what you believe and then we're going to refine those ideas later. That was definitely something that we pulled from the methods course. We clarified confusing vocabulary because you need to be specific because spin and rotate are different terms. We just wanted to make sure that we were clear on the differences and then let me look.

Reece (07:07):
We pulled from the methods course too to have a demonstration of the probe. What we did was we had each student read out the probe and then we had to model it. We had a flashlight which represented the sun or a desk, I think it was a desk bed in the middle of the class and then we had the students either walk around the sun with a basketball to represent the earth. And sometimes I think some of them were spinning and other times it wasn't. And then we used the questioning scaffolds that you provided us and what do other people think about student A's reasoning who would like to add to student A's reasoning? Does anybody have a different opinion? And we wanted to make sure that they referenced or demonstrations back when they wanted to provide evidence.

Reece (07:57):
And then we asked students to reconsider their ideas and we asked if their initial ideas had changed. And then we had students explain their final viewpoints and then not many students changed so we weren't really able to have a discourse where we talked about, "Oh, I disagree because..." But we did add the talk moves to the board in scaffolds that the students could reference them throughout the initial activity. And then at the end we actually didn't reveal the better answer because they were just starting a unit on the solar system. They would find out later. But we explained as long as they had evidence to support their ideas, that's what a good scientific explanation is.

Interviewer (08:50):
And they did mostly, it sounds like talking through.

Reece (08:52):
Yes. They didn't write anything. They just talked through this one.

Interviewer (08:57):
But the only kind of modeling they did was the whole body, the role playing with the balls. Did they like that?

Reece (09:04):
They did. But at times it got a little bit overwhelming because everybody wanted to role play. They were like, "'I don't know why I didn't get a turn and I don't know why I didn't. And we're like, "Well you could be the first one to talk." And they were like, "Well, I wanted to do this." And I was like, okay. It was a little bit hard trying to balance that, but we tried to give everybody a turn.

Interviewer (09:26):
And you mentioned so visual thinking could you say, but you did the you called it the histogram or basically a line, I guess a line chart.

Reece (09:35):
Yeah. A line chart.

Interviewer (09:36):
Yes. What you were doing with the math, do you do a lot of... Is visual thinking emphasized a lot in the math methods course.

Reece (09:45):
Yeah. I would say so we do... Each week everybody comes in and they have their own graph question that we have to plot. And then with a lot of the modeling, the fractions, it's all visual. We do a lot of visual modeling with that.

Interviewer (10:02):
Drawing it out. Interesting. And then when you talked about explaining the terms, could you say a little bit about how you explained them? How did you make it?

Reece (10:18):
Just like first asked students what they thought that it meant. And our students had a pretty good idea of what the words meant, but then we wanted to just make sure that we had a clarification of spin and then sun shining. We talked about the sun's raise kind of, we didn't want to go into too great detail because they're still kind of young. We weren't sure how much they knew, but they had a pretty good idea. We just thought it was important to clarify, before we read the probe, they could have not a visual, but they could imagine what was happening.

Interviewer (10:52):
You did in terms of describing the words. I was trying to think about whether you drew out an image, whether you modeled it with your body, so you use words to explain. Let's do the same thing to pull up your second redirect. This is where you did the can rocket so you touched on that a little bit earlier.

Reece (12:21):
To start our lesson, we did another graph. We did an icebreaker and it said, if you're going to travel to another planet in a rocket ship, what planet should you travel to? That was the first question that we posed. And then we had students come up and plot their answer on the board. And then we asked them why they would travel to that planet and kind of off topic. But they had some really interesting answers as to why they would travel to some planets because they were just starting to learn about the properties of all the different planets. And some of them were like, "Well, one of the planets could float in a bathtub. That's why I want to go to it." And it was just very above a third grade level. I thought I was very interesting. And then before we did the rocket launch, we asked some questions just in case students didn't really have background
knowledge of a rocket launch. And majority of them had seen a rocket launch. I don't think anybody hadn't seen one.

Reece (13:19):
But we just wanted to clarify some of the science behind it so we said, what direction does the rocket travel? Why do you think it travels that way? And what do you think makes the rocket be able to launch up into the air? We just left. We didn't answer those questions. We had students answer those questions to start getting their knowledge and background to start thinking about it. And then we presented the materials to the students and we had each of them examine them a little bit so that they wouldn't fight over, who got to do what? And Harrison and I just did the experiment because we didn't want the students to get injured, but then we transitioned to outside and they were pretty good. We went over expectations before we left. And we said there's other classes going on because our class was in trailers.

Reece (14:12):
And there's that open area that we were able to go to, but there's also trailers around. We were like okay, remember our hallway rules, our sale, which is their PBIS behavior program. We went over all those rules and they were pretty good outside. They just got very excited that when in the rocket launched up into. But then the actual experiment itself, we followed all the steps. It went well. And we did it twice that the students could see if the rock had traveled in another direction or if it launched as high because at first they weren't really sure what to expect. It might not have been paying attention to all the detail, but we had them consider what direction did it launch in?

Reece (14:58):
How fast did it launch? Because our first one I was in charge of it and I was about to go pick it up because I thought it was a da da and it shot up. We were like, "Okay, we have to have another one." But then we went back to the classroom and we had the class do a discussion on what they saw happen. And then we took something from the methods course and we had them draw what they thought had happened. And I made sure before the kids started drawing to draw the non observables. The force of gravity, pretty sure I put air resistance on there too, because I said we want to draw when the rocket's going up and then when it's coming back down. And then I put one of the magnification symbols so that students could draw what they thought was happening inside of the canister. Because there was a lot going on. And then if students were struggling, we asked them several scaffolding questions to help guide their thinking of which way do you think the rocket traveled?

Reece (16:09):
The big question was how did you see the different materials working together during the investigation because a lot of the students weren't sure exactly why it launched. And then after students were done drawing, we had them get with a group and talk about different questions that may not have necessarily occurred during our experiment. But if we were to do another experiment, maybe how it would react differently. We asked how do you think water temperature affects how the rocket launches or how fast the rocket launches do you think the size of the tablet affects how long it takes for the rocket to launch? Do you think the flight path can
be controlled by adding fences to the canister? And what forces do you think are acting on the rocket? Why do you think the rocket comes back down to the ground? Group D or our last set of questions related most to our experiment.

Reece (17:04):
We had students discuss in their groups and they presented their ideas to the class just verbally. They didn't do a big presentation because we didn't have that much time at the end. And then at the end we talked about some of the forces acting on the rock, but we didn't get to talk about them all.

Interviewer (17:20):
I had a couple of things that I thought of while you were talking about that and I realized I might have forgotten to ask you on the questions and I'll go back to that one. But first you were discussing how you included different things to help them withdraw the magnification. Did you demonstrate that or was that on their actual sheet that they were drawing?

Reece (17:50):
No. I demonstrated how to draw it. Because we just handed them a blank sheet of paper and then we said, "We're going to show you some scientific, I don't know I'm blanking down the word, but symbols that you can draw so that you can really hone in on your science thinking how forces act on the can rocket." I drew the gravity, I drew one of the magnification just up on the board so that they could visually reference it. I think it was having it on a paper.

Interviewer (18:23):
You showed it and then it was up on the board?

Reece (18:25):
Yes.

Interviewer (18:26):
Awesome.

Reece (18:27):
Like how you did it in class.

Interviewer (18:32):
And then the other thing I thought of when you were talking about, you've talked a lot, both in your first and second. I wanted to hear you say a little bit about why you think it's important to you've started both your lessons by trying to understand the student's thinking. I wanted to hear you say a little bit about why you think that's important to undo at the very beginning.

Reece (18:53):
I think it's important to establish background knowledge because I know a lot of our students haven't had actual science classes because I'm not sure how the younger grades work at the
elementary school that I was at spring semester, but in fall semester they didn't have science in first, second, I think they didn't start to third grade. It was really important to establish that background knowledge, even something as simple as a rocket launching, maybe a lot of the students hadn't experienced something like that in the past. I think it's really important to establish that background knowledge that all the students are on the same playing field and level almost so they have that back, that scientific knowledge that they can draw from. Because I know some of them might not have had that experience or teaching.

Interviewer (19:44):
Awesome. And this is like say you were discussing getting them to draw and I meant to ask these and I'm wondering if I skipped over them. I've interviewed so many people now that I might be forgetting, but so did I ask you, in what ways do you think drawing is useful as a science teaching strategy?

Reece (20:03):
I think you did.

Interviewer (20:04):
And then did I ask you, what do you think students might have difficulty with regarding drawings? That's the one I think I might have heard.

Reece (20:13):
Yes. I think you did. But I guess with this, like I said before having the students draw so many of them were more excited about drawing as opposed to writing. I know that for sure because they're always like, "Oh, do we have to write?" And they were so excited when they were finally able to express their ideas through drawing, which was amazing to see. And then our one student who has trouble writing, actually a lot of our students have IEPs and have difficulty writing and reading and stuff. And I think this was really beneficial for them because they got to express their ideas in another format and they were finally oh wow I can actually share with the class. I can present my ideas because I actually have something on my paper, which was really cool to see. And then another difficulty was they didn't have enough time because we only had a specific time allotted for the science lesson. If I feel if they would've had more time, their drawings would've been even better. They're good, but I think they could have added more detail and so there's definitely a lot in that time, in the lesson as well.

Interviewer (21:30):
That sounds good. I don't know why as I was listening to you talk I'm like, "Oh, did I remember to do this too?" At the beginning I think because I remember you mentioning your lesson plan I was worried that popped in my head and I skipped over. I have to make sure I use my paper and follow my questions so I don't forget anything. We can probably take down the lesson plan if we don't want that up the whole time I don't know if it, I have a separate screen so I can see it, but I don't know if it's all taking up your laptop so I think we're done with that for now. Thinking
about that, what do you think, if anything you learned about teaching science or science learning by our focus on drawing this semester?

Reece (22:19):
I learned that drawing is definitely a way for students to express their thoughts in science thinking. And a lot of times people are well, it's not the same as writing. But it allows them to probably provide the same amount of detail. It's just in a different format and a lot of people discredit like, "Oh, it's just drawing. It's not as academically taxing as writing, but at the same time it allows students, especially those with disabilities to communicate their ideas to the class and be able to be a part of the conversation. So I think drawing is very beneficial and I will definitely be including it in my future science teaching.

Interviewer (22:56):
Awesome. Nice to hear. And then I think you talked a little bit about it, but did the focus on drawing this semester influence your knowledge of student thinking?

Reece (23:10):
Yes, it definitely did. I'm trying to think.

Interviewer (23:18):
Well, if you can't think of a specific example or something, we can come back to it.

Reece (23:25):
My thinking?

Interviewer (23:26):
No, actually, does it help you understand the student's thinking? Did it change?

Reece (23:31):
Yeah. Now I understand the question, yes. It helped me better understand what my students were thinking because I was actually able to see their thinking. Our students, they're in third grade so they can write, but sometimes it doesn't make sense. Having that drawing probably as well as a written explanation, would've really helped see their thinking visually. And I'm a very visual person. I like drawing. I like hands on things. I think that definitely helped me understand like, oh, this student is lacking knowledge in the fact that the acid tablet reactive with the water, they only put the force. We need to go over what's occurring inside the canister if we were to do another lesson.

Interviewer (24:17):
Those are really good examples. That's what I was looking for. It's always difficult to word these questions in a way that you're going to understand what I'm asking, but I'm not leading too much.

Reece (24:30):
Yes. That helped. Thank you.
Interviewer (24:30):
We're going to transition to, we were thinking about teaching science. I want to do some questions that are addressing just science content knowledge. And so I shared with you, I did a series of your drawings that we can pull that one up. And what we're going to do is first go to... You can do the share it and then do the slide show. And we're going to look at your final drawing to start with.

Reece (24:58):
Let's see.

Interviewer (25:02):
And you can go, the very last one, if you do the slide show and get bigger.

Reece (25:07):
Yes, I see it.

Interviewer (25:09):
I always mess up when I do the share instead of doing the slides show. If you go up to the corner next.

Reece (25:16):
I see.

Interviewer (25:17):
You do that. It'll make it bigger.

Reece (25:19):
Got it.

Interviewer (25:21):
It makes it a little easier to see. This is your final drawing and so take a few minutes. I've been looking at them and I do an interpretation of what you're thinking is based on what I see you draw. But it would help me to hear you talk about it as well. If you could just say a little bit about what you're drawing is trying to show.

Reece (25:47):
There's a lot going on here. I just took elements of our mini lessons and I basically added each of the drawings. I think in the end I had a better idea of what was happening, but I still putting them all together was a little challenging for me, but I think I figured it out. In my washcloth on earth, I drew the magnifications of the different particles. Our solid was our washcloth and our liquid was the water. And then I drew another magnification of what the water molecule looked like. And it was the oxygen and the two hydrogen. And then that's a rain drop all the way over, but it's gravity. Earth was greater than air resistance, which I don't know if air resistance actually acts on
the water. That's why there's a question mark. But I assume since I was traveling down, it might have had a little effect on it. But gravity is greater because that's obviously falls to the floor and then there was the force of twisting.

Reece (27:15):
I guess that run some of the water out as well. And then I think towards the bottom of the washcloth, I put the force of gravity was greater than the force of adhesion. That's why some of them dropped to the ground. And then the washcloth was still a damp so there's still a water layer on the washcloth. And some of it is adhesion to the washcloth, but because I think the force of gravity and the force of the hands was greater. That's why most of the water was able to be rung out. And then on the right side, that's just the wash cloth and space. And let me see, I drew the modification of liquid and water because the molecules, I believe they were the same state of matter on earth as in space. I assume that they stayed the same, not sure now though, that I'm talking about.

Reece (28:18):
And then I drew another magnification of the water molecule and then since there's no gravity or limited gravity, I said that gravity wasn't a force, but the force of adhesion was keeping the wash cloth, the water around the washcloth and I guess the positive was the oxygen molecules were attracted to the washcloth because I guess the washcloth had positive molecules, I don't know.

Interviewer (28:58):
That's how I interpreted that you were thinking that the washcloth had a positive charge that attracted them.

Reece (29:03):
Yes.

Interviewer (29:06):
And then I noticed you did the layer and you have the little individual drops in there, but I didn't interpret that as you thinking there were individual drops that it was-

Reece (29:18):
No. It was just water.

Interviewer (29:21):
Just water. Just a way of showing that there are multiple. That's useful. Now what I want to do is to go through the series so if you went through the first one, that was your very first drawing. I want you to kind of talk about, as you go through is to help me understand how you decided to make certain changes in your drawings each time.

Reece (29:57):
I knew that they're both a solid and a liquid, so that I was sure about. And then I drew gravity acting on the wash cloth because I wasn't sure if gravity was acting on the total wash cloth, but I
think I changed that later. And then for the one on the right, I wasn't sure if there was a force
acting on the water to keep it in, but I knew that it wasn't gravity, so that didn't change from my
first to my last one, but I wasn't quite sure about what force was acting on the washcloth to keep
the water molecules, I guess around the washcloth in space.

Interviewer (30:37):
And you probably have touched on this earlier, but what influence, you did the little
magnification, so I probably know the answer to this, but what influenced you, including that in
your drawing?

Reece (30:48):
Our class sessions with the pipe and the water being bent almost attracted to it. And just all the
experiments that we had.

Interviewer (31:04):
The experiments influenced what you drew. I was thinking about you knowing how to do the
magnification-

Reece (31:11):
That too as well.

Interviewer (31:14):
I have your Cartesian diver with a kind of as a baseline, but that was prior to me doing direct
instruction for the different foundational images. And I felt that what we did influence, but it's
important to make sure that influence.

Reece (31:34):
It definitely influenced that.

Interviewer (31:37):
That was your first one. Unfortunately with the second one, when you move to that one, it has
my sticky notes on it, where I have questions. I thought that I had one that didn't have that, but
when I went through my records, I had just saved the one that I had stuck questions on. How did
you decide to change things for the second one?

Reece (32:01):
For the second one, I didn't consider if there was a layer of water on the wash class. I decided to
shade it in a little bit and I answered back, yes. There's water still in the washcloth. And then you
wrote, do you think that air resistance is important? And I wasn't sure if it was important, but I
guess it was a factor I don't know necessarily if it was super important, but it definitely I guess
worked on the water because I guess if it's falling, it has to have some air resistance and then you
asked, is there droplets or a film? That was just my way of representing water because there
wasn't droplets. There was some little air bubbles, but I don't think that's what those represented
when I initially drew it. And then I drew the charge molecules and in this drawing versus the last drawing because I hadn't considered how that might play a role previously.

Interviewer (33:03):
The second drawing was after we did the work with the water molecules in class. And then your third one is the next one. And I noticed that for everyone's not as much change. But the second one was a big difference from the first one and then the third one.

Reece (33:24):
What I'm noticing is the force of adhesion. I'm trying to think if there's anything else.

Interviewer (33:33):
And I noticed the vocabulary was what you had put in there.

Reece (33:37):
Yes. Might have added, is there a force? I feel the word just, I don't know if that's from the previous one, but I think I asked, is there a force acting on the water molecules that they stay surrounding? That was from the previous drawing.

Interviewer (33:57):
To my eyes, I didn't notice this one in your final one. I feel like most people once they got to the third one that it basically stayed pretty similar to the last one. That's because our last one was just we reviewed and re-watched everything. We took a look at that. I actually asked you this in class, but so we did the written explanation in your notebooks after you drew your final drawing. And my question in what ways do you think drawing your explanation affected what you wrote for your explanation in your notebook?

Reece (34:45):
I think drawing and having these ideas beforehand helped me better constructive explanation because I knew I could look at my drawing and then I would write about my drawing as opposed to just being like, "Oh, well this happened, this happened, this happened." And not having my drawing to look at, I don't think it would've been as robust as an answer because I would have to recall things that we did a couple weeks ago. And I forget sometimes what I eat for breakfast. Just having something to look at visually really helped me organize my thoughts in my opinion.

Interviewer (35:16):
And were there specific aspects of your understanding of this phenomenon? Your understanding about the water forces that were particularly helpful to draw?

Reece (35:29):
Definitely the force of adhesion I think was helpful to understand and draw as well as the water molecules, because previously I wouldn't have even have thought that would've affected how a washcloth acts in space versus on earth. I think that was something that helped.
Interviewer (35:54):
And were there certain aspects of your understanding that are actually easier to write about than to draw?

Reece (36:03):
I'm trying to think. Probably that the washcloth was still damp. That was definitely easier to write than draw. I'm trying to look at my drawing as well. Also how to represent there was no gravity in space that was also easier to write than draw as well. That's all I see.

Interviewer (36:39):
It's good to understand what things are easier to draw about and what did you find easier to write about? And this is a little bit of a switch because we've been thinking about your water drawings, but I wanted to think about just force and motion in general. In what ways, if any, do you think your conceptual understanding about force and motion developed or changed over this semester?

Reece (37:08):
I feel like I have a much better understanding of forces in motion over the course of the semester. What really helped me was your drawings on the board? Being able to actually because again, I'm like very visual and hands on it and really helped to see the diagrams that you drew. I didn't really have a great idea of how it worked at the beginning of the semester because I had taken physics a long time ago and just physics is not my favorite. I just never really understood, but I think having the example of the washcloth, because you don't really think about forces acting on everyday objects. That was really interesting as well. And it helped me better understand that forces act all the time as well.

Interviewer (37:58):
And you gave some specifics. When you were talking about physics, so Jordan took I think the elementary physics class. Did you take that class as well or?

Reece (38:10):
I did, yeah.

Interviewer (38:12):
And she said there was a workbook that that you went walk through. Did you have to draw in that? Because I didn't realize that you-

Reece (38:24):
Yes, but he didn't really explain stuff very well and it was over Zoom too. The only time that we were really drawing was when we were trying to figure out problems, but he didn't actually show us how to draw most of the time because we weren't in a classroom setting. We were on the computer and a lot of our homework too, it would just be multiple choice questions. He didn't need to submit a drawing or submit a written explanation. It was just oh, what's the best answer. I think drawing definitely helps me at least better understand the physics aspect of science.
Interviewer (39:06):
And you talked about me drawing. Did you actively drawing add to that any at all?

Reece (39:15):
Yeah, I think it did because I was able to for example, here the water drop, I was able to look at it and say, "Oh, well the force of gravity has to be greater because it's falling downward and then I guess the force of air resistance would have to be less because it's going down. I think it definitely helped me personally drawing as well.

Interviewer (39:40):
Good to hear. And you can take down your drawings now too because I know when you have it up, you're not looking at me. You might looking at your drawing. I don't know. So our last questions are related to affect. Beliefs and attitudes. The first one that I want to ask is now that you've finished the semester, how prepared do you feel for teaching the three strands of science? That's the life science or physical science. How prepared do you feel for teaching the three strands of science in the elementary classroom?

Reece (40:12):
I feel very prepared now, especially with the physics, because again, that was not really a strong suit, but because we spent a lot of time going over it, I think I definitely feel more confident now to teach that to younger students.

Interviewer (40:26):
That was my first one was in what ways are there some specific strategies or things that you feel particularly more effective or prepared for teaching?

Reece (40:38):
I feel more prepared for teaching hands on experiments than last semester. Because we were kind of just like, "Oh, here's a lesson plan that you have to do, make it hands on." Now I understand how to plan a hands on investigation and think about things that I really wouldn't have thought about like procedures in the hallway when you're doing it safety procedures, because that's not something that I would generally think about. I think that's definitely helpful as well.

Interviewer (41:05):
What are some ways that you feel you need more preparation? Can you think of some things that you'd like to know more about or feel you need to know more about?

Reece (41:16):
I think just not being from North Carolina, the North Carolina curriculum in general and that's just me being able to research it. I'm comfortable with the science topics themselves, but just understanding how they fit in the curriculum and definitely the field trip project helped a lot because I was able to say like, "Oh, this fits with this strand in the third grade curriculum or so being able to really look at those standards and understand them."
Interviewer (41:47):
That's good to hear. And do you think that you're... And you mentioned earlier about physics, isn't your favorite, but now you feel prepared. Does your feelings of preparation differ based on the science strand?

Reece (42:02):
Well, now I definitely feel more prepared with physics. I've always felt very comfortable with biology and more life science. That's definitely more my thing. I do feel more comfortable still with teaching those, but I'm not as afraid to teach physics now. That's good.

Interviewer (42:22):
With the biology, is it an interest aspect of it or what makes you feel comfortable about that?

Reece (42:29):
Yeah, it's probably more of interest aspect. I just always have liked life science, animals. My mom's a physical therapist, so I've always grown up when I was three I would fall down and I'd be like, mommy I hurt my patella. Three year old says that, but I was always very interested in anatomy as well.

Interviewer (42:53):
And so that kind of covers my last was, can you say more about why you feel this way about your interest for life science?

Reece (43:00):
I just felt more exposed to life science at a young age. I was able to understand it better.

Interviewer (43:09):
Makes sense. And do you envision incorporating drawing in as a strategy in your own teaching one day?

Reece (43:17):
Yes, definitely. I think it's an excellent way because I'm actually getting my certain special ed as well. I hope to work in an inclusion setting. I think it's a really great way for students, especially with those who are disability or ELL, especially because they can't necessarily write their thoughts all the time in English to communicate their ideas to the teacher. And you can look at a drawing and be like, "Oh the student understands forces, but they don't necessarily understand a chemical reaction." For example, in canned rocket experiment.

Interviewer (43:50):
I think you kind of answered both. I had probing questions. Could you say more why and you mentioned because you're going to be working in special education setting to support them communicating in ELL and then you gave some examples about how you would incorporate them. Communicating and then my last question is for you, is that, how did you feel about you drawing for your own learning this semester?
Reece (44:17):
Even though I'm not the best drawer, I think it definitely helped me communicate my ideas because with drawing, you can just go back and erase if something doesn't necessarily fit your thinking anymore. But with writing you'd have to go back and especially if it's on paper, cross out and edit and I just think drawing was definitely an easier way to think about my ideas before I wrote them out. Because I could visually see what I was thinking.

Interviewer (44:45):
What are some ways you found it challenging?

Reece (44:49):
Drawing. It was definitely challenging because I'm again, not the most artistic person. Just being able to actually draw things a water drop that's a little challenging for me, but the labels and stuff made it easier for me to be able to participate. So I appreciate having the labels.

Interviewer (45:14):
The labels and ideas. It sounds like you find it challenging because you're not sure of your drawing ability. And then ways that you think the drawing was beneficial to you?

Reece (45:28):
I think it was beneficial because again, I could just draw whatever I was thinking and then go back throughout the semester and edit my drawing and I think that's a lot easier to do as opposed to editing writing, because you can just erase and then redraw or add specific elements, especially if you did a pencil.

Interviewer (45:48):
Very good. And then do you think that your attitude about drawing changed over the semester from the beginning when we did our first Cartesian diver to the end when you did your final drawing?

Reece (46:00):
Yes. I was a low suspicious of drawing at first and science, but now I think it's really, really beneficial and I actually enjoyed it towards the end because I was able to just add to my drawing and it was like a relaxing way to add it. Wasn't as high stakes as writing. I could just add my ideas and not have to go back and do a ton of editing.

Interviewer (46:28):
And Jordan mentioned this and I happen to think, when you were in school, you said you didn't for the physics so much, but back in elementary or high school, did you draw any at all for any of your sciences?

Reece (46:45):
Not that I can think of.
Interviewer (46:47):
I was curious about that. Well, I think that's all of my questions that I wanted to go through. Anything you want to add that maybe I didn't touch on that you'd want to. Awesome. I'm going to pause that.