The Relationship Between Discipline-Specific Subject Matter Knowledge and Discipline-Specific Science Teaching Efficacy of Elementary Teachers

Douglas Ball
Utah State University

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THE RELATIONSHIP BETWEEN DISCIPLINE-SPECIFIC SUBJECT MATTER KNOWLEDGE AND DISCIPLINE-SPECIFIC SCIENCE TEACHING EFFICACY OF ELEMENTARY TEACHERS

by

Douglas Ball

A dissertation submitted in partial fulfillment of the requirements for the degree of DOCTOR OF PHILOSOPHY in Education

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Logan, Utah

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ABSTRACT

The Relationship Between Discipline-Specific Subject Matter Knowledge and Discipline-Specific Science Teaching Efficacy of Elementary Teachers

by

Douglas Ball, Doctor of Philosophy
Utah State University, 2023

Committee Chair: Colby Tofel-Grehl, Ph.D.
Department: School of Teacher Education and Leadership

Because science teaching efficacy correlates with instructional methods, teaching engagement, and pedagogical choices, improving science teaching efficacy becomes critical for improving science teaching of young children. Science teaching efficacy also varies by discipline for elementary teachers: physical science teaching efficacy tends to measure lower than life science. This discrepancy leads to elementary teachers engaging in less effective science teaching practices with physical science. A major factor that influences science teaching efficacy is subject matter knowledge. Subject matter knowledge impacts science teaching efficacy because when teachers understand their content proficiently, they express confidence in their ability to provide students with accurate and meaningful instruction. Given that both subject matter knowledge and science teaching efficacy are domain specific, understanding the relationship between discipline-specific subject matter knowledge and discipline-specific science teaching
efficacy will aid in developing interventional support to improve levels of science teaching efficacy by improving discipline-specific subject matter knowledge. However, little is known about the relationship between discipline-specific levels of subject matter knowledge and science teaching efficacy. Using an explanatory sequential mixed methods design through a multiphase data collection process, this study sought to establish what, if any, relationship exists between discipline-specific subject matter knowledge and discipline-specific science teaching efficacy across physical and life sciences for in-service elementary teachers. Phase one included collecting quantitative data from web-based surveys using the Science Teaching Efficacy Belief Instrument (STEBI) and Misconceptions-Oriented Standards-Based Assessment Resources for Teachers (MOSART) as a subject matter knowledge instrument. The STEBI instrument was adapted to physical and life sciences. Afterwards, phase two included qualitative data from interviews to inform our understanding of (1) the teacher’s perceptions of potential sources of their discipline-specific science efficacy beliefs and (2) information regarding connections between their efficacy beliefs and classroom practices. Findings show that physical science and life subject matter knowledge are predictors of physical science teaching efficacy when accounting for teaching years and grade. Physical science measured lower for personal science teaching efficacy and subject matter knowledge compared to life science. Teachers with higher efficacy and knowledge report using more student-centered and adapted lessons while also taking more ownership of student learning.
PUBLIC ABSTRACT

The Relationship Between Discipline-Specific Subject Matter Knowledge and Discipline-Specific Science Teaching Efficacy of Elementary Teachers

Douglas Ball

Because a teacher’s confidence in their ability to teach science is associated with instructional methods and their persistence in the face of challenges, improving science teaching confidence becomes critical for improving science teaching of young children. Science teaching confidence also varies by discipline for elementary teachers: physical science teaching confidence tends to measure lower than life science. This discrepancy leads to elementary teachers engaging in less effective science teaching practices with physical science than life science. A teacher’s subject matter knowledge influences their confidence in their ability to teach that subject. Subject matter knowledge impacts science teaching confidence because when teachers understand their content proficiently, they express confidence in their ability to provide students with accurate and meaningful instruction. Both subject matter knowledge and science teaching confidence are specific to disciplines. Understanding the relationship between discipline-specific knowledge and discipline-specific science teaching confidence will aid in developing teacher development training to improve levels of science teaching confidence by improving discipline-specific subject matter knowledge. However, there is currently little research on the relationship between discipline-specific levels of subject matter knowledge and science teaching confidence. This study sought to understand what, if any, relationship
exists between discipline-specific subject matter knowledge and discipline-specific science teaching confidence across physical and life sciences for in-service elementary teachers. Teachers took an online survey to assess their knowledge of physical and life science subjects and their confidence in teaching those subjects. Following the survey, eleven teachers were interviewed to understand their perceived sources of discipline-specific science teaching confidence and how they taught life and physical science in their classrooms. Results show that physical and life science subject matter knowledge are predictive factors of physical science teaching confidence. Teachers tend to measure lower in physical science than life science for both subject matter knowledge and confidence in teaching physical science topics. Teachers with low science knowledge and science teaching confidence tend to rely more on district-provided resources and presentations than those with more knowledge and teaching confidence who adapt lessons to meet student needs. Highly confident teachers are also more likely to hold themselves responsible for student learning outcomes.
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# CONTENTS

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRACT</td>
<td></td>
<td>iii</td>
</tr>
<tr>
<td>PUBLIC ABSTRACT</td>
<td></td>
<td>v</td>
</tr>
<tr>
<td>ACKNOWLEDGMENTS</td>
<td></td>
<td>vii</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td></td>
<td>xi</td>
</tr>
<tr>
<td>CHAPTER I: INTRODUCTION</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Science Teaching Efficacy Across Physical Science and Life Science</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Subject Matter Knowledge</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Impact of Low Teacher Subject Matter Knowledge</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>The Problem</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Research Questions</td>
<td>10</td>
</tr>
<tr>
<td>CHAPTER II: REVIEW OF RELATED LITERATURE</td>
<td></td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>Theoretical Framework</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Subject Matter Knowledge</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>Science Teaching Efficacy</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>Interactions Between Subject Matter Knowledge and Science Teaching Efficacy</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>In-Service Teacher Interventions</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>Pre-Service Teacher Interventions</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>Limitations of Measuring Subject Matter Knowledge</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>Discipline-Specific Subject Matter Knowledge and Discipline-Specific Science Teaching Efficacy</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>Next Generation Science Standards</td>
<td>31</td>
</tr>
<tr>
<td></td>
<td>Conclusion</td>
<td>33</td>
</tr>
<tr>
<td>CHAPTER III: METHODS</td>
<td></td>
<td>36</td>
</tr>
<tr>
<td></td>
<td>Study Design</td>
<td>36</td>
</tr>
<tr>
<td></td>
<td>Positionality Statement</td>
<td>42</td>
</tr>
<tr>
<td></td>
<td>Phase 1</td>
<td>44</td>
</tr>
<tr>
<td></td>
<td>Phase 2</td>
<td>53</td>
</tr>
</tbody>
</table>
## LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 1</td>
<td>Subject Matter Knowledge Question Selection Summary</td>
<td>46</td>
</tr>
<tr>
<td>Table 2</td>
<td>Hierarchal Regression Results for Physical Science Personal Science Teaching Efficacy</td>
<td>61</td>
</tr>
<tr>
<td>Table 3</td>
<td>Hierarchal Regression Results for Life Science Personal Science Teaching Efficacy</td>
<td>61</td>
</tr>
<tr>
<td>Table 4</td>
<td>Pearson Correlation Coefficients Between All Survey Items</td>
<td>62</td>
</tr>
<tr>
<td>Table 5</td>
<td>Mean Differences Between Life Science and Physical Science</td>
<td>64</td>
</tr>
<tr>
<td>Table 6</td>
<td>Teacher Participant Demographics by Category</td>
<td>66</td>
</tr>
<tr>
<td>Table 7</td>
<td>Theory-Driven Codes (First Cycle) with Examples</td>
<td>69</td>
</tr>
<tr>
<td>Table 8</td>
<td>Emergent Codes (Second Cycle) with Examples</td>
<td>78</td>
</tr>
<tr>
<td>Table 9</td>
<td>Shared Characteristics Within Each Interviewed Group</td>
<td>80</td>
</tr>
<tr>
<td>Table 10</td>
<td>High SMK/High STE Quotes of Student-Centered Instruction</td>
<td>84</td>
</tr>
<tr>
<td>Table 11</td>
<td>High SMK/High STE Group Findings by Interview Question</td>
<td>87</td>
</tr>
<tr>
<td>Table 12</td>
<td>Low SMK/High STE Group Findings by Interview Question</td>
<td>97</td>
</tr>
<tr>
<td>Table 13</td>
<td>High SMK/Low STE Group Findings by Interview Question</td>
<td>103</td>
</tr>
<tr>
<td>Table 14</td>
<td>Low SMK/Low STE Group Quotes on Teaching Physical vs Life Science</td>
<td>111</td>
</tr>
<tr>
<td>Table 15</td>
<td>Low SMK/Low STE Group Findings by Interview Question</td>
<td>112</td>
</tr>
<tr>
<td>Table 16</td>
<td>Qualitative Findings that Corroborate and Explain Quantitative Results</td>
<td>119</td>
</tr>
</tbody>
</table>
CHAPTER I
INTRODUCTION

Deborah Ball (1991) noted “Teachers cannot help children learn things they themselves do not understand” (p. 8) Science teaching efficacy (STE), a domain-specific type of self-efficacy, refers to the belief in one’s science teaching abilities to effectively teach science and yield positive student learning outcomes (Bandura, 1997; Blonder et al., 2014; Riggs & Enochs, 1989). STE influences teacher behaviors such as persistence and time spent teaching, making it very influential when trying to improve instruction (Pajares, 1992).

Self-efficacy, and specifically STE, provides an important lens through which to examine teachers’ instructional behaviors. By understanding the ways that STE influences teacher action, researchers can improve classroom practices. In describing some practices affected by science teacher self-efficacy, Hoy et al. (2009) notes:

Teachers who lack confidence in their knowledge of science content and pedagogy tend to deemphasize or avoid science teaching or teach using transmissive as opposed to inquiry methods. (p. 632)

For example, if an elementary teacher possesses low STE, they will teach science less often or for shorter periods of time (Harlen & Holroyd, 1997; Hoy et al., 2009). Additionally, they will likely rely on worksheets, more procedurally scripted teaching tools, and more didactic forms of instruction, leaving students devoid of inquiry learning opportunities and skills (J. C. Marshall et al., 2009). Inquiry activities are opportunities that engage students in formulating their own questions, testing their ideas, and taking ownership through student-designed investigations. These skills of asking questions and
testing ideas through student-designed experiments are highly critical science skills that students need to develop (National Research Council, 2012). Thus, there is a crucial need for highly efficacious science teachers who engage in inquiry practices. Because teachers who lack STE engage students in less inquiry, a critical science skill, this study seeks to understand factors of STE.

Despite efforts to improve STE, problems remain with teacher STE between and across disciplines within science teaching. Most research and intervention programs at the elementary level focus on pre-service teacher efficacy and science in general (Bleicher & Lindgren, 2005; Liang & Richardson, 2009; Menon, 2020). Fewer efforts focus on in-service teacher efficacy for discipline-specific science subjects. However, elementary teacher STE differs by discipline. Of particular note, STE measures lower in physical science than in life science (Al Sultan et al., 2018; Yilmaz-Tuzun, 2008). Al Sultan examined 49 pre-service teachers using the STE Beliefs Instrument (STEBI) to find that physical STE was the lowest among efficacy scores between life science and physical science. Similarly, Yilman-Tuzun used a different self-reporting survey revealing in-service elementary teachers felt least confident in teaching physics or chemistry concepts compared to biology concepts because they felt they knew least about physical science. Differences in STE are important because the Next Generation Science Standards (NGSS) require integrated disciplinary science knowledge and the ability to apply disciplinary science knowledge across disciplines (e.g., energy as a crosscutting concept). Thus, addressing STE for science as a general subject is no longer sufficient to meet the needs of the NGSS, which requires students and teachers to make connections
between disciplines (NGSS Lead States, 2013). A deep understanding of any science
discipline requires a reasonable understanding of other science disciplines.

As elementary teachers engage in science lessons, they will use less effective
teaching practices in disciplines where they report less confidence (Blonder et al., 2014).
Teachers with high STE tend to plan more, are more organized, are willing to try new
methods, and persist at teaching science (Jones & Leagon, 2014). Conversely, teachers
with low STE, plan less, are less organized, are unwilling to try newer strategies, and
unable to persist when challenges arise. Consequentially, these differences in practices
lead to fundamentally different instructional and learning experiences across disciplines.
This differential instruction creates a lopsided learning environment for students that
favors only teacher-confident science subjects. As noted in the earlier example, when
teachers demonstrate low STE, they tend to teach science for less time. This truncated
instructional time being discipline specific can, over time, lead to significantly decreased
learning opportunities for students. If teachers tend to have lower STE in physical science
than life science, we can expect students to receive less instruction in physical science
over the course of elementary school than life science. This is borne out in the research of
Harlen and Holroyd (1997) wherein they found that teachers avoided teaching physical
science because they were less confident of their knowledge of physical science
compared to life science. Addressing disproportionate instruction is critical because the
NGSS requires students to use discipline-specific content knowledge across other
scientific disciplines, such as applying physical science cross-cutting concepts across all
life science and earth science subjects (e.g., energy; National Research Council, 2012).
Elementary teachers feel less capable in teaching physical science than life science. This specific professional lack of confidence is lower STE. One major factor impacting STE is subject matter knowledge (SMK), which includes knowledge of science concepts that make up the required content for a specific subject. SMK influences STE because the teacher’s level of content knowledge has impacted their confidence to provide accurate and meaningful instruction on the subject (Roth, 2014). Elementary teachers are aware of their SMK deficiencies (Capps et al., 2012) and, as a result, tend to engage coping strategies such as avoiding teaching science or using more scripted activities (Appleton, 2003). These practices of coping are driven by a perceived lack of SMK and are notably more prevalent with physical science than life science. Because of the relationship that exists between overall STE and science SMK generally, the purpose of this study is to explore discipline-specific STE and the potential impacts of discipline-specific subject matter across and between physical and life sciences.

Given that science SMK influences STE (Menon & Sadler, 2016), and STE differs by science discipline (Yilmaz-Tuzun, 2008), the instructional strategies engaged across disciplines differ. Teachers who struggle to comprehend science rely on scripted activities, thereby neglecting more effective science teaching methods such as inquiry-based techniques (Rollnick et al., 2008). These teachers rely more on procedurally scripted activities for physical science than life science (Harlen & Holroyd, 1997). Intervention programs and research around how factors improve STE have been primarily at the pre-service teacher level rather than the in-service teacher level (Menon & Sadler, 2016; Yilmaz-Tuzun, 2008). Multiple studies have shown that pre-service
teachers are less comfortable teaching physical science when compared to life science (Brown et al., 2014). However, to date, little is known about how subject-specific efficacy and knowledge interact when focusing on in-service teachers.

**Science Teaching Efficacy Across Physical Science and Life Science**

Elementary teachers have less STE in physical sciences compared to life sciences (Yilmaz-Tuzun, 2008). Factors contributing to this difference in STE between life and physical sciences include prior school science experiences, lack of subject comprehension, and perception of relevance (Al Sultan, 2020). As a result of needing to teach many subjects, elementary teacher training programs often require relatively few science courses (Yilmaz-Tuzun, 2008). Consequently, teachers who only take the few required science courses in college express less confidence in teaching science compared to those who take more than the required number (Cantrell et al., 2003; Luft et al., 2013).

In a mixed methods study, Al Sultan interviewed 55 teachers to understand factors contributing to their STE. A common theme emerged that revealed teachers felt life science was more relevant to their everyday encounters which led them to having more confidence in the life science over physical science. Moreover, many conventional physics courses teach laws and equations without actually connecting those scientific relationships found in the equations back to everyday life experiences (Nilsson & van Driel, 2011). Thus, teachers are less likely to make the connection to relevant everyday physics, and therefore, more likely to feel less confident teaching physics concepts because of the perceived irrelevance.
Subject Matter Knowledge

There are multiple adaptations of knowledge models that center on Shulman’s (1987) model, but most are comprised of three types of knowledge: (1) SMK, (2) pedagogical content knowledge (PCK), and (3) curricular knowledge. SMK (sometimes referred to as content knowledge) is defined as a teacher’s understanding of concepts and skills around a topic such as science (Shulman, 1987). In Shulman’s words, PCK encompasses “the most useful ways of representing and formulating the subject that make it comprehensible to others (Shulman, 1987, p. 9).” Curricular knowledge is the knowledge a teacher has about the available instructional tools and curriculum they can use in their instruction. These three types of knowledge interact with each other, but this study will focus primarily on SMK as a factor of PCK and STE, which both influence teacher practice. Without SMK, the teacher’s PCK to effectively teach science becomes limited (Chan & Yung, 2015; Rollnick et al., 2008; van Driel & Meirink, 2014). As such, SMK serves as an underpinning to PCK. In addition, SMK is also known to directly affect a teacher’s efficacy, albeit with some mixed results (Catalano et al., 2019; Menon & Sadler, 2016; Swackhamer et al., 2009). Nonetheless, many studies using an intervention to increase science SMK and STE have been shown to be effective (Jones & Leagon, 2014; Lumpe et al., 2012).

Impact of Low Teacher Subject Matter Knowledge

Elementary teachers who have incomplete SMK of the science content they teach tend to employ several coping strategies (Akerson, 2005; Appleton, 2003). For example,
one such strategy noted in the literature is teaching as little of the topic as possible (Harlen & Holroyd, 1997). When this occurs, measurable differences between instructional time can be observed (Harlen & Holroyd, 1997). These differences in instructional time can manifest in tremendous learning opportunity losses for students over time. By way of example, imagine if teachers with low SMK engage in just 10 minutes less instruction than their high SMK colleagues per science lesson over the course of a school year and assuming that science is taught twice a week, students whose teachers have low SMK could theoretically receive as much as 720 minutes less instruction a year. Further, when examined in relation to other instructional coping strategies engaged by teachers with low SMK, a dire picture emerges for students who live in these classrooms. As noted earlier, teachers with low SMK also rely more on procedural and scripted science kit activities (Rollnick et al., 2008). These learning opportunities lack richness and meaningful engagement with scientific phenomena as laid out by the NGSS (e.g., Marshall et al., 2009). As such, these students lack essential inquiry and scientific reasoning opportunities in their science learning. These lesser opportunities coupled with less instructional time manifest significant inequity student opportunities to learn and engage in science.

Teachers with low SMK also exhibit similar misconceptions to their students (Kind, 2014). Scientific misconceptions (or alternative conceptions) are ideas and notions about how the world works that are not aligned with the scientific community’s body of knowledge (Treagust, 1988). Scientific misconceptions limit a teacher’s abilities to respond to student inquiries effectively (van Driel et al., 2014). Halim and Meerah (2002)
concluded that science teachers who lack content knowledge are unable to anticipate student misconceptions and instead reinforced student misconceptions through their explanations. In contrast, teachers that possess more SMK tend to do this better and demonstrate an ability to provide students with multiple perspectives or analogies of a concept to help students make connections between scientifically sound ideas (Johnson et al., 2012).

The relationship between SMK and STE indicates that an elementary science teacher’s SMK is correlated with their STE (Durmus et al., 2016; Jones & Leagon, 2014). Evidence in the literature demonstrates the positive gains of SMK on STE, such as interventions that provide professional development, specialized college courses, or endorsement courses to improve a teacher’s content knowledge (Menon & Sadler, 2016; Swackhamer et al., 2009). Such SMK improvement interventions are effective at helping the teacher to be more confident towards teaching science (Bergman & Morphew, 2015; Menon & Sadler, 2016).

The Problem

Despite evidence of a correlation between science SMK and STE, little about their relationship is clearly defined. Gains in general STE are noted when discipline-specific SMK is increased through interventions (Catalano et al., 2019). For example, Catalano et al. investigated the effect of discipline-specific SMK on general STE for elementary teachers to find that a moderate negative correlation exists between SMK and STE across disciplines. Teachers who had high STE, measured with Science Teaching
Efficacy Beliefs Instrument, scored lower on the Science Beliefs test measuring general science SMK and included questions in life, physical, and earth sciences. Notably, the participants of this study included STEM specialists, and in-service teachers enrolled in graduate programs. This negative correlation between SMK and STE demonstrates the Dunning-Kruger effect, which is that less-knowledgeable people tend to overestimate their abilities (Kruger & Dunning, 1999). This is important because historically research demonstrates a positive correlation between SMK and STE. Teachers that are more self-efficacious and lack the science understanding are at greater risk of making instructional errors and fail to notice that they are making such errors (Kruger & Dunning, 1999).

Given the juxtaposition of various findings, it is critical to better understand the relationship between SMK and STE for discipline-specific domains.

Much of the literature analyzing the effect of SMK on STE has primarily been regarding general science knowledge or general STE. Few studies have investigated discipline-specific sciences. Those that have, have explored the relationship between general science SMK and discipline-specific STE (Al Sultan et al., 2018). In addition, most of the research methodology used to measure STE or SMK relies on quantitative methods to analyze these relationships. Qualitative methods of interviews or open-ended survey responses regarding a teacher’s beliefs about science subjects and how they teach are sparse. Open-ended teacher participant responses articulate a clearer perspective as to what the teacher believes concerning their efficacy towards a subject and what they do with those beliefs in the classroom. Qualitative interview data will provide a window into a teacher’s perceptions of where they believe they have developed their confidence in
teaching science subjects. Moreover, their responses could reveal self-awareness of their discipline-specific science efficacy beliefs and if they’re aware of any sources of those beliefs.

Given the need to increase elementary teachers’ STE to improve their science teaching practices, this study will explore the relationship between discipline-specific STE and SMK across and between both life science and physical science, respectively.

The purpose of this study is to gain a better understanding about the relationship between life science SMK and STE as well as the relationship between physical science SMK and STE, and the differences between them. Specifically, the following research questions will be addressed.

**Research Questions**

1. What, if any, relationship exists between elementary teachers’ discipline-specific subject matter knowledge and teaching efficacy for life science and physical science?

2. In what ways do teachers’ self-efficacy beliefs related to physical science knowledge, life science knowledge, and science pedagogy relate to their understandings of their classroom practices?
CHAPTER II

REVIEW OF RELATED LITERATURE

Factors such as teacher self-efficacy and content knowledge influence teacher practice. Teachers’ instructional practices are significant moderators of students’ academic achievement (National Research Council, 2012). Thus, understanding factors that impact teachers’ instructional practices can improve outcomes for students. The influence of teacher practice on student performance is as accurate in science as it is in any subject. Two notable factors that influence teachers’ instructional practice are teacher efficacy (Lumpe et al., 2012) and teacher knowledge (Appleton, 2003; Sadler, Sonnert, et al., 2013). Social cognitive theory (SCT) asserts that these variables affect individuals’ behaviors (Bandura 1997; Schunk & Pajares 2004; Zimmerman 1998). It positions people as self-regulating, self-reflecting, organizing, and proactive individuals instead of individuals shaped only by biological or environmental factors (Pajares, 2002). Self-efficacy (SE) is the belief that one is capable of carrying out specific behaviors (Bandura 1997 Schunk & Pajares 2004, Zimmerman 1998). With teachers facing complex dynamics within their classrooms, their self-efficacy becomes an essential factor in understanding classroom instruction and practice.

When elementary teachers struggle with implementing effective instructional strategies in science, their students have lower science achievement (Appleton, 2003; Cofré et al., 2015; Harlen & Holroyd, 1997; Rollnick et al., 2008). Elementary teachers often lack sufficient science content knowledge to competently teach the content required of them (Appleton, 2003; Harlen & Holroyd, 1997). According to Shulman (1987),
teaching a subject takes knowledge of at least three discrete types; Shulman distinguishes between SMK, PCK, and curricular knowledge. SMK consists of the facts and concepts within the domain of a specific topic. PCK includes how a teacher manages a classroom and enacts a lesson through various instructional strategies. Curricular knowledge includes knowledge about the instructional materials and curriculum the teacher can use in teaching. Research on the relationship between SMK and science teacher efficacy indicates that science SMK and science PCK both positively correlate with STE (Menon & Sadler, 2016; Park & Oliver, 2008; Swackhamer et al., 2009). However, when we look closer, research on the discipline-specific subject matter and discipline-specific teaching efficacy are sparse. This study seeks to examine the potential relationship between discipline-specific SMK and discipline-specific STE. I hypothesize that an increase in discipline-specific SMK results in an increase in STE for specific science subjects.

**Theoretical Framework**

This work is grounded in SCT using both the affective construct of STE and Shulman’s (1986) construct of SMK. SCT states that learning, and a person’s development, are a function of the dynamic interplay between environmental factors, personal factors, and behavior. These factors influence one another in a relationship known as triadic reciprocity (Bandura, 1989; Pajares 2002; Schunk & Pajares, 2004). Triadic reciprocity is the relationship between each of the three SCT factors that can influence the others reciprocally. For example, environmental factors may influence behavior, and behavioral factors may influence the environment.
Bandura (1997) defined self-efficacy as “beliefs in one’s capabilities to organize and execute the courses of action” (p. 3). Self-efficacy is the beliefs that influence a person’s behavior in terms of how much time and effort they will put into a task, the stick-to-it-iveness when obstacles arise, as well as how that person solves problems (Pajares, 1992). Science education literature is replete with examples where teaching self-efficacy is measured as either personal teaching efficacy or outcome teaching efficacy according to Bandura’s (1986) scholarship. In this work, personal teaching efficacy is the primary focus of exploration as it pertains to Bandura’s claim that teachers’ motivation to act is based on their belief of “whether they can actually execute the necessary activities” (p. 392).

Bandura’s (1997) construct of self-efficacy is also context, skill-, and task-specific, as demonstrated in research by others (Bong, 2006). Since Bandura’s original definition of self-efficacy, the definition includes other contexts such as STE (Leagon & Jones, 2014). STE is the belief in one’s science teaching abilities. Although the term science teaching self-efficacy has been used in the literature (Blonder et al., 2014; Jones & Leagon, 2014), STE is also a popular term in the literature denoting the same construct (e.g., Bleicher, 2004; Catalano et al., 2019; Durmus et al., 2016; Menon & Sadler, 2016; Taştan Kirik, 2013)

Because STE, like self-efficacy, is context-specific (Bandura, 1997), the level of SMK a teacher has can affect the perceived ability to teach science effectively (STE) and thus impact the amount of time and methods the teacher devotes to science instruction (Swackhamer et al., 2009; Tschannen-Moran et al., 1998).
SCT purports there are four types of experiences that influence self-efficacy. Those four types of experiences are (1) mastery experiences, (2) vicarious experiences, (3) persuasory experiences, and (4) physiological experiences. Mastery experiences are experiences of learning and performing the target task. Vicarious experiences are observing another engage and succeed in doing the targeted task. Persuasory experiences are encouraging or discouraging feedback regarding one’s performance of the target task. Physiological experiences are those experiences that occur on a physical level, such as anxiety.

Mastery experiences are the successful or failed results from a performed task. Of the four self-efficacy factors, mastery experiences provide the most potent source of efficacy information (Bandura, 1977; Tschannen-Moran & Hoy, 2001). For science teachers, mastery experiences include their learning of subject matter across multiple science disciplines (cognitive mastery) and their instructional performance in the classroom (enactive mastery). Science teaching, specifically, requires targeted science subject matter and pedagogical knowledge appropriate for the grade. Cognitive mastery is attained when teachers perceive success in understanding either SMK or pedagogical knowledge. Teachers learn science subject matter through the entirety of a teacher’s life.

Despite this, a teacher’s college years allow teachers to zero in on content and pedagogy specific to their future choice of teaching grades. If a science teacher has successfully performed well in their science classes in the past, they will have greater confidence in teaching (Bleicher & Lindgren, 2005) and learning the subject (Knaggs & Sondergeld, 2015). As an example, Bleicher and Lindgren investigated pre-service
teachers’ science content understanding and their reflection of that conceptual change throughout the course. Their study reveals that science teaching confidence can increase as a result of both the teacher understanding the subject matter better and reflecting on the success of their improved understanding.

Another example of a mastery experience that influences SE is the teacher-perceived success of their teaching performance because of student achievement (Palmer, 2011). Student achievement provides external validation in support of a teacher’s instructional performance, thereby positively affecting their self-efficacy and beliefs (Bandura, 1982) towards teaching science. Evidence of this was a study conducted by Palmer (2002), who demonstrated that elementary teachers who had external validation of their science teaching techniques through successful student performance developed greater self-efficacy towards science teaching. The teachers in Palmer’s (2011) study perceived their PCK to be effective as a result of student achievement.

The second most influential factor to teacher self-efficacy is vicarious experience (Palmer, 2011), which involves teachers seeing other teachers succeed or fail in similar circumstances. Learners often look to models of others’ successes and failures around the same tasks when gauging how well they may succeed when performing that task. Developing confidence through observation of models is considered most effective when the observer perceives the modeler’s ability as similar to the observer’s ability (Bandura, 1977). Vicarious experiences include teachers observing another teacher use an instructional skill, watching a teacher deliver a lesson to students, teachers self-recording while teaching (self-modeling), or teachers imagining themselves using effective
instructional practices in a classroom (cognitive self-modeling; Bandura, 1997). Knaggs and Sondergeld (2015) examined the impact of vicarious experience on SE through the use of teachers observing and reflecting on video recordings of themselves teaching science, as well as the effect of live teacher presentations. The authors conclude that these vicarious experiences had a positive influence on the perceived PCK and STE of the teachers.

Verbal persuasion experiences occur when teachers receive verbal feedback or support from administrators, other teachers, students, parents, and the community. This feedback is less impactful on teacher self-efficacy when compared to mastery and vicarious experiences but can provide efficacy “boosts” (Bandura, 1977; Tschannen-Moran & Hoy, 2001). Verbal persuasion’s influence, though dependent on the perceived credibility of the persuader (Zimmerman, 2000), is also less effective in maintaining or developing teaching efficacy for career teachers than it is for pre-service teachers (Tschannen-Moran & Hoy, 2007). Nevertheless, for in-service teachers, feedback from student enthusiasm and engagement can significantly boost teacher efficacy (Flores, 2015; Mulholland & Wallace, 2001). Furthermore, student engagement and excitement can stem from the teacher’s pedagogical knowledge level (Keller et al., 2017; Palmer, 2002). PCK, therefore, has the potential to mediate teacher efficacy. For pre-service teachers, these persuasory experiences can come from feedback given from college science and teaching methods course instructors as these instructors evaluate the pre-service teacher performance.

Last, physiological or emotional states also affect teacher self-efficacy. These
states include the levels of stress, anxiety, or excitement a teacher experiences (Bandura, 1997). An increase in PCK can also improve a teacher’s attitude and enjoyment towards teaching science. For example, Van Aalderen-Smeets and Van Der Molen (2015) provided a 6-month, hands-on, inquiry-based science course to 64 elementary teachers from 18 different schools. The intervention course’s focus was to engage teachers with effective science pedagogical knowledge and instructional tools while also self-reflecting on their attitudes throughout the course. The authors concluded that the intervention increased PCK and enjoyment towards teaching science, lowered science teaching anxiety, and as a result increased their STE.

Subject Matter Knowledge

Carter (1990) defines knowledge as the total knowledge a teacher has that, at any given moment, influences her or his actions. According to Verloop et al. (2001), this does not imply that all knowledge a teacher has will actually affect every action. Not every idea is acted upon or brought into action. There is, however, a reciprocal relationship between what the teacher does, says, thinks, and believes, and what is known as teacher’s knowledge (Verloop et al., 2001). SMK, also known as content knowledge, is the content, or conceptual understanding, specific to a domain of knowledge such as science (Shulman, 1986, 1987). Shulman (1986) describes this knowledge domain as including both substantive knowledge and syntactic knowledge. Substantive knowledge includes the myriad ways that concepts and principles may be organized into an understanding. Syntactic knowledge includes how claims and ideas are warranted as acceptable within
the subject area and how they are set apart from other subjects. SMK serves as an underpinning of another type of needed teacher knowledge (Shulman, 1987) as well—PCK. Teacher SMK is known to influence PCK (Rollnick et al., 2008), instructional practices (Sanders et al., 1993), teacher self-efficacy beliefs (Ball, 1991; Menon & Sadler, 2016; Swackhamer et al., 2009), as well as student learning (Sadler, Sonnert, et al., 2013).

At the elementary level, research has shown elementary teachers to be limited in science SMK (Burgoon et al., 2011) and mathematics SMK (Wilkins, 2008). Moreover, teachers vary in their effective practices and knowledge across subjects, such as mathematics and English language arts (Cohen et al., 2018). Much of the SMK a teacher acquires comes from implicit and explicit learning opportunities through environments such as (1) the teacher’s own K-12 school learning, (2) teacher education and professional development (PD) programs, and (3) teaching experiences (Friedrichsen et al., 2009; Munby et al., 2001). A teacher’s education prior to career-teaching includes teaching methods coursework as well as general content coursework in college. During career-teaching years, teachers will acquire knowledge through classroom experiences and professional development.

In efforts to improve teacher SMK, some scholars have argued for increasing content through more college coursework (Velthuis et al., 2014), while others have contested that more college coursework is not the key; instead, science content is better studied in practice as a teacher (Traianou, 2006). However, research demonstrates slightly mixed results as to whether, or how much, a teacher’s SMK changes over their
career as a result of teaching. Some studies show teaching experience improves SMK (Nixon et al., 2019), while others have shown that experience does not affect SMK (Mulholland & Wallace, 2001). Nixon et al. demonstrated that elementary teachers’ science SMK increases in the first half of their career for topics in their assigned grade level. Professional development interventions have shown to be successful in helping teachers develop better SMK (Donna & Hick, 2017; Wheeldon, 2017). Although professional development can improve SMK, Goldschmidt and Phelps’s (2010) study on the effect of an English language arts PD demonstrates that practical classroom experience can also hinder the retention of some of the SMK acquired through PD.

The literature on elementary teacher practices reveals that teachers who exhibit higher levels of SMK spend more time teaching science (Jones & Carter, 2007), construct better scientific explanations from multiple perspectives (Childs & McNicholl, 2007; Johnson et al., 2012), use less procedural teaching techniques to aid in helping students make connections to big ideas (Rollnick et al., 2008), and integrate content (Gess-Newsome & Lederman, 1995). Practices such as these have been deemed effective science teaching methods and yield significant student achievement in science (Hodges et al., 2013; Johnson et al., 2012). The literature affirms that low-SMK teachers rely on line-by-line instructional procedures (Rollnick et al., 2008) and rely heavily on activities that work for the teacher rather than bolster the student learning outcome (Appleton, 2003). Notably, Appleton found in a study on beginning elementary teachers an emergent pattern of science teaching avoidance either in the form of postponement or outright not teaching science regularly. Halim and Meerah (2002) concluded that teachers who lacked
content knowledge were unable to anticipate student misconceptions and lacked the needed capacity to address science misconceptions. This inability to anticipate student misconceptions becomes problematic given that elementary teachers carry many misconceptions that also mimic their students’ misconceptions (Burgoon et al., 2011). Therefore, improving teacher SMK is essential to better science learning opportunities for students.

To ameliorate elementary teachers’ limited science SMK, science teacher educators and administrators have sought to implement teacher training that improves science SMK. For example, Danusso et al. (2010), when discovering that teachers did not understand the role of scientific models, implemented an effective intervention program to help pre-service teachers understand the iterative nature and use of scientific models. Other science teacher educators have attempted to develop specialized discipline-specific courses for pre-service teachers in order to boost their science-specific SMK (Bleicher & Lindgren, 2005; Menon & Sadler, 2016; Nilsson & van Driel, 2011). In-service professional development programs have successfully used content-specific courses to develop specific subject matter (Rollnick et al., 2013). Several intervention studies that focused on the method of science content delivery found the following methods to be successful in SMK gains: the use of concept maps as a way of meaning-making (Rollnick et al., 2013), a hands-on and constructivist rich-discussion approach (Bleicher & Lindgren, 2005), or engaging teachers in real-world field science research (Dresner & Worley, 2006).
Science Teaching Efficacy

Self-efficacy is a construct with far-reaching influences on many factors that affect teaching strategies, teaching ability, and the desire to improve as a teacher (Blonder et al., 2014). It is widely accepted within the literature that STE directly influences a teacher’s practice (Jones & Leagon, 2014).

Bong (2006) asserts researchers are demonstrating that self-efficacy depends on specific contexts, skills, and tasks. Since Bandura’s original definition of self-efficacy, the definition has thus been broadened to include domain-specific and context dependent efficacy types such as STE (Klassen et al., 2011). STE is the belief in one’s own abilities to teach science successfully. Although science education scholarship has used the term science teaching self-efficacy (Blonder et al., 2014; Jones & Leagon, 2014), STE is also a popular term in the literature referring to the same construct (e.g., Bleicher, 2004; Catalano et al., 2019; Durmus et al., 2016; Menon & Sadler, 2016; Taştan Kirik, 2013).

Science Teaching Efficacy Impact on Teacher Practice

Several studies have examined the effect that STE specifically has on science instruction in the classroom. Marshall et al. (2009) studied over 1,000 teachers to understand how STE influences science practices teachers engaged their students in and found that teachers with higher self-efficacy tend to use more inquiry-type activities in the classroom and perceived to spend more time with such activities. The results of the study demonstrate this effect was even more pronounced for elementary teachers than middle school teachers. Outside of what practices teachers engage in, teachers with low
STE teach science less frequently and less time than teachers with higher STE (Harlen & Holroyd, 1997; Hoy et al., 2009). Harlen and Holroyd also note that less-efficacious teachers teach science subjects in lesser amounts of time than teachers with more STE. In addition to what teachers do in the classroom, teachers with higher STE are also shown to have high expectations for their students (Angle & Mosley, 2009).

Factors of Science Teaching Efficacy

Much of the literature on studies investigating influential factors on STE focus on teacher knowledge, teacher skills, and teaching experience in years. Many scholars have reported the positive effect that SMK has on STE either by measuring their knowledge using a concept inventory instrument (Ates & Saylan, 2015; Catalano et al., 2019; Johnston & Ahtee, 2006; Nilsson & van Driel, 2011; Schoon & Boone, 1998; Yilmaz-Tuzun, 2008) or by number or type of courses taken in college (Bleicher & Lindgren, 2005; Cantrell et al., 2003; Korb et al., 2005; Tosun, 2000).

In addition to SMK shaping STE, the types of skills and teaching methods a teacher develops can also impact how confident the teacher is towards teaching science. Lumpe et al. (2012) developed professional development around helping teachers develop the 5E method of science teaching, which features strategies for students to engage, explore, explain, elaborate, and evaluate. As a result of the PD, teacher participants displayed significant gains in STE. Similar studies also demonstrate that effective science teaching practices, such as scaffolded student-directed inquiry, contribute to gains in STE (Liang & Richardson, 2009). In a study by Knaggs and Sondergeld (2015), pre-service teachers reported a perceived gain in STE because of the
instructor’s effective use in modeling science pedagogy.

Some scholars have also looked at the impact that teaching experience has on STE. For example, Durmus and Ogul (2016) found that in-service teachers have higher STE than pre-service teachers. They further added that teachers with at least ten years or more had higher STE than those with less experience in years. This finding is in line with Tschannen-Moran and Hoy’s (2007) conclusion that the years of experience a teacher accumulates is positively correlated with a teacher’s self-efficacy.

**Interactions Between Subject Matter Knowledge and Science Teaching Efficacy**

Science SMK influences the confidence an elementary teacher has in implementing quality instructional practices in science. Teachers’ perceptions of their own prior successes influence the amount of effort, persistence, and time they devote towards science (Tschannen-Moran et al., 1998). When a teacher has strong SMK it helps develop their confidence in their teaching abilities, thereby improving STE (Bergman & Morphew, 2015; Morrell & Carroll, 2003). Teachers who possess strong STE utilize more effective instructional approaches than those with little confidence (Jones & Leagon, 2014). For example, teachers who have a high level of self-efficacy tend to be more innovative (Guskey, 1988), use more student-centered strategies in the classroom (Ramey-Gassert et al., 1996) and strive more to improve their teacher skills (Tschannen-Moran & Hoy, 2001).

A large number of scholars assert the level of science SMK a teacher possesses is
positively correlated with STE (Al Sultan et al., 2018; Bleicher & Lindgren, 2005; Cantrell et al., 2003; Lumpe et al., 2012; Menon & Sadler, 2016; Nilsson & van Driel, 2011; Nivalainen et al., 2013; Schoon & Boone, 1998; Swackhamer et al., 2009; Ulmer et al., 2013; Weld & Funk, 2005). Of these eleven studies investigating the effect of science SMK on STE, only four of them examined the effect with in-service teachers (Lumpe et al., 2012; Nivalainen et al., 2013; Schoon & Boone, 1998; Swackhamer et al., 2009). Among the four in-service teacher studies, only one (Catalano et al., 2019) yielded a significant negative correlation between SMK and STE. For this reason, it is worth noting how it differs from the other studies. Catalano et al. compared elementary teachers’ science content knowledge using the Science Belief’s instrument to their STE using the STEBI instrument. The participants were 82 in-service and 27 pre-service elementary teachers. There was no significant difference in science SMK scores between in-service and pre-service teachers, though in-service teachers did score higher on their STE scores than pre-service teachers. However, when comparing the science SMK scores with the STE scores, a correlation test showed a negative, moderate, significant correlation revealing that the higher the STE score, the lower the content knowledge. This result was true for both groups combined. However, this negative correlation is at odds with the other studies that also incorporated concept inventories showing higher content knowledge associated with higher STE (Al Sultan et al., 2018; Bleicher & Lindgren, 2005; Durmus et al., 2016; Schoon & Boone, 1998). The negative correlation is also alarming because teachers with high self-efficacy may be more susceptible to resisting change in instructional methods given how overconfident they can also be in their
pedagogical knowledge (Tschannen-Moran et al., 1998). One notable difference of Catalano et al.’s (2019) study is data from both pre-service and in-service teachers was grouped together, when most other studies investigated effect of SMK on STE chose to analyze the two groups separately. However, given that 75% of participants in the study were in-service teachers, it still begs the question as to what factors may have influenced these results, and whether in-service teachers and their differences in STE with pre-service teachers influenced results. The authors of the study offer no explanation around this matter. All other studies examining the association between SMK and STE for pre-service or in-service teachers reveal that a higher SMK, measured directly or indirectly, indicate a higher STE (Al Sultan et al., 2018; Appleton, 1995; Bleicher & Lindgren, 2005; Cantrell et al., 2003; Menon & Sadler, 2016; Nilsson & van Driel, 2011; Ulmer et al., 2013; Weld & Funk, 2005).

**In-Service Teacher Interventions**

While researchers and science teacher educators have come to understand factors of STE and the importance of STE, they have developed intervention methods to improve STE through various means. Among the studies that investigated the relationship between science SMK and STE, much of the research relied on the effect of a science content course or the number of science courses taken to measure a teacher’s SMK (Cantrell et al., 2003; Durmus et al., 2016; Lumpe et al., 2012; Nilsson & van Driel, 2011). As an example of how science content coursework affected STE, Nillson and van Driel implemented an 8-week course in physics for 40 elementary teachers and tracked their
progress with interviews and storylines throughout the course. The instructional practices of this workshop focused on student discussions and highly collaborative experiments where large groups of 13-14 teachers proposed and carried out their experiment designs. The experiments were video-recorded and discussed for explicit teaching reflection. Many participants in the study remarked how their understanding of how the content fits within their curriculum context boosted their perceived self-confidence in teaching the content. A similar outcome from qualitative data was reported by (Swackhamer et al., 2009) after in-service teachers completed a series of content courses. The teachers in the Swackhamer et al. study related how their perception of their improved science understanding gave them confidence in their ability to teach science more effectively.

Summer professional development programs have become a way to target changes in STE for in-service teachers. Lumpe (2012), for example, implemented a large-scale summer professional development that involved approximately 450 teachers attending a 2-week course for a total of 80 hours of training. The training focused chiefly on teachers developing science inquiry practices around the 5E model learning cycle (Bybee & Landes, 1988) while also learning science content. The results were significant gains in STE, with the number of attendance hours positively correlated to STE. A positive correlation was also present between hours attended and fourth and sixth-grade student learning outcomes, demonstrating increased SMK due to professional development. In other efforts to improve STE through PD, Palmer (2011) found that when teachers are presented with content mastery and verbal persuasion experiences over 2 years, the teacher’s perception of their science understanding, coupled with feedback
from teaching observations, provided a significant increase in their STE. Some researchers document using additional college courses to teach content knowledge alongside pedagogical knowledge for in-service teachers to bolster STE (Swackhamer et al., 2009).

**Pre-Service Teacher Interventions**

Several other studies used intervention approaches or modified methods courses to investigate how STE can change due to change in a pre-service teacher’s science SMK. Bleicher and Lindgren (2005) specifically demonstrated that an elementary science methods course geared towards more constructivist, hands-on, minds-on, and discussion-rich activities significantly increased both the STE and SMK of the participants. A similar investigation by Menon and Sadler (2016) also adjusted a science methods approach to include more problem-based, collaborative, hands-on activities, and rich discussions. Using a mixed-methods analysis with a quantitative conceptual understanding survey, the STEBI instrument, and interviews regarding STE, both SMK and STE increased with a positive correlation between the two (Menon & Sadler, 2016). The authors believe the correlation exists because the students reported they were engaged in the content, able to remember content, and thus the students held positive perceptions toward the subject itself. This positive perception of the subject’s content matter and the ability of the teachers to recall concepts led to a positive perception of the teacher’s ability to teach the content (Menon & Sadler, 2016).

For pre-service programs, teacher educators have sought to engage teachers in
developing best practices such as guided inquiry, alongside content knowledge, as a means to improve STE (Avery & Meyer, 2012; Cervato & Kerton, 2017). Providing pre-service teachers with more field experience early on in their teacher programs has also improved STE (Cantrell et al., 2003; Flores, 2015). This need for earlier field-teaching experience becomes noteworthy given that Velthuis et al. (2014) demonstrates that teachers improve and develop STE the most during years 1 and 2 in teacher education programs, compared to years 3 and 4. Furthermore, given that an increase in SMK fosters STE, several authors have demonstrated that additional science content courses designed for teachers in pre-service programs can also significantly increase teacher STE (Bergman & Morphew, 2015; Deehan et al., 2017). Cantrell et al. reported that the number of science content courses that pre-service teachers took prior to student teaching also affected their pedagogical knowledge and STE, as reported by the pre-service teachers.

**Limitations of Measuring Subject Matter Knowledge**

It is essential to note the limitation of measuring SMK through coursework or hours of professional development. Other factors may have affected teachers during the coursework or PD that shaped their STE in addition to science SMK. As evidence, Knaggs and Sondergeld (2015) conducted a study to understand how science content courses can improve pre-service teachers’ efficacy. They found that by including self-efficacy embedded experiences in a course, such as verbal feedback and pedagogical and content mastery experiences, teachers perceived both their SMK and STE improve over
the course. Knaggs and Sondergeld concluded that improved science content understanding is what the teachers perceived as one of the main contributing factors to their improved confidence in teaching science. However, the course did not rely on SMK alone but instead incorporated improving both SMK and PCK. The PCK or even the instructor’s approach may have had an effect. This result is in line with findings from Morrell and Carroll (2003), who propose that SMK alone does not always automatically improve STE. Morrell and Carroll purport that for low SMK teachers, an increase in science content can improve STE, but when a teacher is initially efficacious, their STE change becomes dependent on additional factors. Additional factors include pedagogical approaches by the course instructor and teaching science content intended for the elementary teachers (Cervato & Kerton, 2017).

Given the limitations of measuring SMK through science content courses or teacher training hours, other scholars have sought to measure the relationship of science SMK and STE more directly using SMK instruments such as concept inventories (Al Sultan et al., 2018; Bleicher & Lindgren, 2005; Catalano et al., 2019; Schoon & Boone, 1998). Many of these instruments probe the teacher’s understanding in comparison to common science misconceptions. For instance, Schoone and Boone conducted a study with 619 teachers who took a multiple-choice survey designed to uncover misconceptions and compared it with their STE belief (STEBI) questionnaire score. The authors concluded that teachers who held a higher number of alternative conceptions also had lower STE.
Discipline-Specific Subject Matter Knowledge and Discipline-Specific Science Teaching Efficacy

A few scholars have more recently investigated either discipline-specific SMK on general STE (Catalano et al., 2019), or general science SMK on discipline-specific STE, as was the case with Al Sultan (2020). In efforts to categorize levels of STE as more than just high, medium, and low, Al Sultan et al. (2018) sought to distinguish levels of STE by science discipline. They examined knowledge and efficacy beliefs held by 49 pre-service teachers using the Test of Basic Scientific Literacy survey to measure SMK and the Beliefs about Teaching (BAT) instrument to measure discipline-specific STE. Their conclusion was that general science SMK was positively correlated to discipline-specific STE for physical, life, and earth sciences. Furthermore, the study also demonstrated a significant difference between general STE and subject-specific STE. When comparing discipline-specific STE for the three science fields, they also found physical STE to be significantly lower than both life science and earth STE for pre-service teachers.

Catalano et al. (2019) examined the discipline-specific SMK’s effect on general STE for pre- and in-service elementary teachers through the measure of STEBI’s subscales: personal science teaching efficacy (PSTE) and science teaching outcome expectancy (STOE). They concluded that pre-service teachers had higher overall STE than in-service teachers, and there existed a negative correlation between science knowledge and STE. However, the negative correlation was an effect observed through the combined sample of both the pre- and in-service teacher participants. Also, participants of the study tended to score higher in life science content knowledge.
compared with physical and earth science.

No study has explicitly measured discipline-specific SMK directly with discipline-specific STE. The previously mentioned studies are the closest to doing such. There have been a few teacher intervention studies demonstrating that when SMK in one discipline improved, so did general STE (Appleton, 1995; Cervato & Kerton, 2017; Knaggs & Sondergeld, 2015). Other studies suggest that discipline specific STE also improved through interventions that targeted building a teacher’s SMK and pedagogy, implying that discipline specific SMK is a possible factor of discipline specific STE (Deehan et al., 2017; Lumpe et al., 2012). Notwithstanding, no study to date has measured the direct effect of discipline-specific SMK on discipline specific STE for in-service or pre-service elementary teachers. In other words, it is unknown as to whether an increase in a teacher’s knowledge of a specific science subject will influence that teacher’s specific science discipline teaching efficacy.

**Next Generation Science Standards**

One of the reasons that discipline-specific knowledge and teaching efficacy are vital is the way current science teaching standards integrate discipline-specific science topics across all science fields. These current teaching benchmarks, also known as Next Generation Science Standards (NGSS), have been adopted or adapted by 44 states within the U.S. while other states are greatly influenced by them. The crux and purpose of the standards are to integrate science and engineering skills with disciplinary content knowledge and concepts, known as crosscutting concepts, that span their utility across all
sciences (NGSS Lead States, 2013). The content knowledge, known as disciplinary core ideas (DCIs), is divided into three subcategories: life science, physical science, and earth and space science. The science and engineering practices (SEPs) that students use and develop as skills include modeling, analyzing and interpreting data, planning and conducting investigations, communicating evidence-based explanations, and others. The conceptual tools to aid the way students think through science, known as crosscutting concepts (CCCs), including the use of patterns, cause and effect mechanisms, scale, proportion, quantity, system models, energy, structure and function, as well as stability and change. Together the DCIs, CCCs, and SEPs form the integrated three dimensions of NGSS. The shift from previous standards is for teachers to prioritize having students build their content knowledge through science practices and crosscutting concepts rather than rote or merely didactic teaching methods. Traditionally, students focused mostly on learning disciplinary core ideas through lectures, worksheets, and the occasional confirmatory science experiment to expose students with a hands-on activity.

Historically, K-12 science has paid little attention to how students develop their understanding through evidence-based reasoning, evaluation, modeling, and critique (National Research Council, 2012). NGSS are intended for students to integrate all three dimensions regularly. In this way, students of science are becoming better everyday scientists who understand how to use a set of skills to make sense of their worlds rather than walking and talking knowledge repositories.

To accomplish the purpose and mission of NGSS, teachers will need to know how to adapt lessons, engage students in scientific inquiry, and have the knowledge base to
integrate disciplinary science topics across other disciplines. For example, when students and teachers know how to model the physical science of energy transfer within and between systems, they can make sense of more complex natural phenomena that occur in many of the other science disciplines. A Framework for K-12 Science Education summarizes the research necessary for the development and implementation of NGSS and describes one purpose of the DCIs as a “key tool for understanding or investigating more complex ideas and solving problems” with “broad importance across multiple sciences (National Research Council, 2012, p. 31).” To successfully teach NGSS, teachers will need robust SMK across each discipline and the confidence to adapt and integrate new practices into their instruction, as well as meet their students’ diverse science learning needs.

**Conclusion**

In summary, research indicates that science teachers who are highly self-efficacious tend to engage students in more inquiry-based activities (J. C. Marshall et al., 2009), spend more time teaching science (Hoy et al., 2009), teach for longer periods of time (Harlen & Holroyd, 1997), and have high expectations of their students (Angle & Moseley, 2009). One main factor of STE is science SMK. A large majority of studies examining the association between science SMK and STE of elementary teachers show there to be a positive relationship between the two constructs (Al Sultan et al., 2018; Bleicher & Lindgren, 2005; Cantrell et al., 2003; Lumpe et al., 2012; Menon & Sadler, 2016; Nilsson & van Driel, 2011; Nivalainen et al., 2013; Schoon & Boone, 1998;
Swackhamer et al., 2009; Ulmer et al., 2013; Weld & Funk, 2005). Given this relationship, researchers have observed successful interventions to build a teacher’s science SMK through professional development (Lumpe et al., 2012), teachers completing more science content courses (Cantrell et al., 2003), or taking a specialized science content course (Menon & Sadler, 2016).

Last, some studies have looked at the comparison of discipline-specific STE to find physical STE lower than life STE (Al Sultan et al., 2018; Yilmaz-Tuzun, 2008). Furthermore, when comparing discipline-specific SMK between life science and physical science, elementary teachers tend to perceive they have lower SMK in physical science than life science as the reason they have lower confidence in teaching physical science compared to life science (Al Sultan, 2020). This lack of teaching efficacy in physical science provides evidence as to why elementary teachers either teach less of physical science than life science or use less effective “coping” mechanisms to teach physical science (Akerson, 2005; Harlen & Holroyd, 1997).

There are relatively few studies investigating the association between science SMK and STE for elementary in-service teachers (Catalano et al., 2019; Lumpe et al., 2012; Swackhamer et al., 2009). Much of this research has relied on the number of science content courses taken, type of specialized science content course taken, or PD along with a pre and post-test to measure SMK. However, these methodologies for measuring SMK have shown to have other conflicting factors, such as the instructional approach or acquired pedagogy from the course, that effect the teacher’s STE, not just SMK (Menon & Sadler, 2016; Morrell & Carroll, 2003). Given this, some studies, albeit
very few, measured the relationship between SMK and STE more directly through instrumentation (Al Sultan et al., 2018; Bleicher & Lindgren, 2005; Catalano et al., 2019; Schoon & Boone, 1998). Of these, only one studied the effect with both in-service and pre-service teachers (Catalano et al., 2019) yielding a moderate negative correlation between science SMK and STE, contradicting much of the previous research. To date, no study has investigated the effect science SMK on STE with only in-service elementary teachers while using validated instruments to measure science SMK and a correlation more directly between science SMK and STE.

Knowledge and teacher efficacy, however, are considered domain-specific constructs (Shulman, 1986; Tschannen-Moran & Hoy, 2001). Unfortunately, little has been done to understand the effect of discipline-specific SMK on discipline-specific STE. In other words, little is known about whether physical science content knowledge affects physical STE or life science knowledge on life STE. Knowing that teaching practices depend on STE, and that physical science is taught less, or with less effective strategies than life science, it becomes critical to understand how discipline-specific SMK effects discipline-specific STE in order to teach both disciplines with equal treatment. This disproportionate instruction can lead to disproportionate student learning. The effort to balance instructional time and efforts across disciplines becomes critical knowing that NGSS requires students to use discipline-specific cross-cutting concepts found in physical science to understand phenomenon found in other disciplines such as life science (e.g., energy; National Research Council, 2012).
CHAPTER III

METHODS

Study Design

This study uses an explanatory sequential mixed methods design (Creswell & Plano Clark, 2018) through a multiphase data collection process. Mixed methods analysis provides an opportunity to understand the nuanced relationship between teachers’ discipline-specific beliefs and practices in a way that is richer than either a qualitative or quantitative study would alone. Furthermore, mixing data types allows a triangulation of quantitative survey data with interview results.

This study occurred in two phases, conducted sequentially. Phase one sought to answer the first research question using quantitative data from web-based surveys. Phase two sought to answer the second research question through interviews in order to expand upon the quantitative results obtained from phase one. These phases are outlined in further detail below.

Participants

The participants recruited for the study were teachers who taught Utah fourth- or fifth-grade science content at the time of the survey, with at least one year of teaching experience. These two grades teach the most physical science and life science content according to state-adopted standards that use grade band endpoints outlined in A Framework for K-12 Science Education (National Research Council, 2012). Furthermore, these grade-level standards rely on crosscutting concepts that integrate physical science
concepts (e.g., energy) into all science disciplines. This study excluded first-year teachers because less experienced teachers (under 1 year) typically still carry their pre-service teacher beliefs and knowledge (Nixon et al., 2019). Last, the crosscutting concepts used with NGSS are organized to rely on concepts and skills that are learned in earlier grades; therefore, these two grades are more likely to utilize the crosscutting concepts that involve some physical science when compared to earlier grades. To screen for teachers that met these criteria, the survey asked teachers questions before letting them proceed to the rest of the survey.

An *a priori* statistical power analysis was conducted for sample size estimation. To achieve a medium effect size in this study of 0.15 (Cohen, 1988), with an alpha = .05 and power = 0.8, the projected sample size needed with this effect size (GPower 3.1) was approximately $N = 98$ for a regression analysis. Thus, the targeted sample size was 123 to allow for some expected attrition. The recruitment email (see Appendix A) with the Qualtrics survey link was distributed by email to approximately 2,200 fourth- and fifth-grade teachers from 11 different school districts within the same state. The districts varied in a mix of urban, suburban, and rural populations. Teachers were given an incentive with a one in six chance of being rewarded with a $50 Amazon gift card for those who completed the survey. A total of 247 teachers responded to the survey (11% response rate), while only 139 teachers (56% of responders) qualified and completed the survey from start to finish. Participants took, on average, 40 minutes to complete the full survey. Participants for interviews were selected based on their SMK survey scores as well as their STE across both life and physical science. The research institution offered a
$10 Amazon gift card for each interview participant. Of the survey participants, 25 qualified for an interview and 11 willingly participated each in a 20-minute interview. The interview participants were grouped across four categories of selection criteria delineated within the qualitative methods section to follow.

**Significance of Elementary Context**

This study sought to understand how disciplinary knowledge influences teaching efficacy and teacher practices at the elementary level. There are two significant reasons for focusing the study on elementary teachers rather than secondary or post-secondary teachers. First, elementary teachers are subject matter generalists in their preparatory college studies and teaching. While secondary and post-secondary teachers typically develop expertise in a specific subject area over time, elementary teachers are expected to teach a wide range of subjects, which means they may not be experts in all of them. As a result, there is a risk that they give partiality to certain subjects or topics in their instructional choices and content. This is a concern because it can lead to students not receiving a well-rounded education. An evaluation of whether and where elementary science teachers show bias in their instruction is especially needful in light of past literature on discipline imbalance with elementary science instruction (Roth, 2014).

The second significant reason for understanding fourth- and fifth-grade teachers is because this is when the NGSS teaching standards begin to show an interdisciplinary reliance between life and physical science that carries into future grades. For example, fourth-grade students begin to unravel the concept of energy and make sense of how energy is measured, what energy is, and eventually take this crosscutting concept of
energy and use it to understand other phenomenon across various sciences and throughout future grades.

The nature and structure of elementary education centers on the generalist model of instruction. This model means that elementary teachers are the sole teacher in a self-contained classroom, teaching all core academic subjects, such as math, science, language arts, and social studies (Reys & Fennell, 2003), rather than content specialists akin to middle and high school teachers. Even reading specialists, who may be an exception, typically only support teachers specializing in assisting a select few students with interventional lessons instead of teaching the whole class. In addition, some scholars advocate for departmentalizing subject areas in the upper elementary grades to improve the transition to middle school (Chan et al., 2009) or bolster content area instruction. However, much of the elementary generalist teacher model prioritizes young children’s psychological and emotional well-being (Hood, 2010). As Hood argues, children learn best when they have stability and a strong relationship with the teacher, which typically develops when students have only one teacher. Elementary education scholars also add that self-contained classrooms better meet children’s social and emotional needs because teachers have more time to get to know “the whole child” (Heathers, 1961).

Despite the limitations of what college teaching preparation programs offer pre-service elementary teachers, this study focuses on the science education literature’s assessment of what children need to learn across each grade band to contribute and succeed in society as scientifically literate citizenry. This need forms the purpose of the Next Generation Science Standards that most states expect elementary teachers to teach.
in the U.S. For children to succeed in becoming scientifically literate, they need to learn the practices and skills of scientists and engineers in addition to content knowledge.

This knowledge and set of skills progress linearly, where each grade adds upon what the child has learned in grades prior in what the Framework for K-12 Science Education calls grade band progressions. A lack of complete and well-rounded learning in one grade leads to difficulty in the future grade’s intended learning outcomes. Concepts not only build, but they progress in a way that overlaps to make sense of naturally occurring phenomena. Some of these overlapping concepts that help learners to better understand phenomena are known as crosscutting concepts. This progression starts to take root in fourth and fifth grade when teachers first introduce the crosscutting concept of energy to students, along with a wider variety of disciplinary science concepts than in previous grades (life, physical, and earth sciences).

One example of the ramifications of low elementary teacher SMK in physical science is student misconceptions in physical science, given that students mirror teacher misconceptions (Burgoon et al., 2011). Several elementary physical science topics carry over into future grade levels and across the science disciplines. In a Framework for K-12 Science Education, the goal of each NGSS disciplinary core idea is to meet criteria that “have broad importance across multiple sciences or engineering disciplines.” Further, these concepts would also “provide a key tool for understanding or investigating more complex ideas and solving problems.” For example, we see the intersection of these two criteria with the physical science concept of energy. One definition of energy is the ability to move something or cause change. The 3-5 grade progression of standards
within NGSS includes the concept that energy can transfer through collisions, light, sound, heat, and electric currents. Within life science, for the same grade band, are the concepts that for plants to grow and animals to move, they need energy. Understanding how energy moves and transforms within an ecosystem is more easily understood when a student understands what types of evidence for energy transfer are observable in that ecosystem (heat, light). Understanding this concept allows the student to navigate more complex food webs more easily, reasons for them, and make sense of how animals survive in various environments. This example demonstrates how a physical science principle can provide a tool for understanding more complex ideas while also serving as a possible framework for solving problems in life science, not just in the current grade but throughout future grades.

Although this study does not measure the nature of crosscutting concepts, life and physical science concepts taught in these grades, such as energy, serve as foundational underpinnings of a child’s science education for the following decade of school until they graduate. Aside from the cross-disciplinary goal of science concepts, NGSS organizes core content topics of each subject area to persist in an increasingly deeper and more meaningful manner across the progression of grade levels. Students who are limited in understanding a few topics are more likely to struggle between disciplines, especially across grades.

Given that in-service elementary teachers learn science content and pedagogy as they advance in their careers (Nixon et al., 2019), it is surprising to see a discipline-specific gap in knowledge and teaching efficacy that remains persistent across pre-service
and in-service elementary teaching. Elementary teachers may be gaining SMK and PCK but are not closing the gap between the subject-area knowledge discrepancy.

**Positionality Statement**

While completing this dissertation study, I am also in my ninth year as a high school physics teacher interested in understanding how physical science is perceived, taught, and learned by teachers and students. I understand the impact of a robust K-12 physical science education on everyday life experiences. I also recognize there is potential for my personal bias throughout this study, given my lens. My original assumption as an early doctoral student about science education was that science education in elementary and secondary schools was taught as evenly as possible between life and physical sciences across the grades. However, I soon came across literature that claimed otherwise. It was then that I took an interest in understanding how elementary teachers taught and perceived physical science topics. Having developed a great love of physical science from my elementary teachers as a child, I recognize the life-changing influence a teacher can have on children.

Furthermore, I view my physical science lens as a strength that I bring to science education research and a limitation at times. Because I have little experience in elementary education outside of research, I acknowledge that I am somewhat of an outsider looking in. Although I recognize the literature highlighting the differences between how elementary teachers teach and understand various science topics, I fully acknowledge that differences or deficiencies do not often come from ill-intentions of the
teacher’s own doing. Instead, higher institutions, social currents, and other external factors play a prominent role in the values, content knowledge, and pedagogy that all teachers develop in their preparation coursework.

In addition, I recognize my science background knowledge and how I developed much of that knowledge while attaining an undergraduate degree in physics instead of a teaching degree like many elementary teachers. Aside from content and pedagogical knowledge attained from a degree, my knowledge has developed through years of teaching physics, Advanced Placement (AP) physics, and concurrent enrollment (college credit) physics courses in a high school setting. Because of that knowledge, my perspective can influence how I believe physics concepts should be taught or learned in a K-12 classroom. As a secondary teacher researching elementary teachers, I am conscious of the effect that my lens may impose on how I interact with interview participants and conduct this study. The amount of science instruction and attention to a single subject that a secondary teacher experience is vastly different from that of an elementary teacher trained to teach multiple subjects with the same group of students over the school year. This difference limits my understanding of the reasons for elementary teacher instructional and planning decisions.

Last, given that I am a male researcher, there may be unique dynamics with what the all-female interview participants choose to share about their teaching experiences. For example, when prompted, participants may feel less inclined to divulge details about their true efficacy beliefs, the nature and source of those beliefs, or actual classroom practices. However, given my identity, background, knowledge, and beliefs, not once were the
interviewees or other participants of this study informed of my position as a high school physics teacher or my physics degree background.

**Phase 1**

**RQ 1:** What, if any, relationship exists between elementary teachers’ discipline-specific SMK and teaching efficacy for life science and physical science?

**Instrument**

The first phase of data collection utilized an online survey in Qualtrics. This survey consists of questions taken from the Misconceptions-Oriented Standards-Based Assessment Resources for Teachers (MOSART) concept inventory instruments for both life science and physical science. These instruments determine the teachers’ SMK level for each science discipline. These concept inventories are ideal for this study because of their acceptance and validation within the literature for approximating teacher SMK (Sadler, Coyle, et al., 2013). Sadler et al. reports the instrument’s reliability score using Cronbach’s alpha to be between 0.45 and 0.85 across 15 field tests. Sadler et al. also reports the instrument to be valid under the Messick (1989, 1995) validity criteria for each item.

As each survey addresses a wide range of content knowledge intended for secondary and college-level student understanding, only questions that address content related to the Next Generation Science Standards for grades four and five were included. These questions were selected with assistance from elementary grade-band content experts which include three elementary science education researchers. The SMK portion
of the survey is 20 questions long, with 10 questions in life science and 10 in physical science.

The questions selection process is as follows in order of priority. First, I prioritized selecting questions that fit both past and current state standards for both fourth and fifth grades. The MOSART surveys are separated into a K-4 and 5-8 grade survey for both physical and life sciences. Each of the original MOSART instruments contains 20-25 questions. According to the student correct-response percentages, both physical science MOSART surveys were more difficult for students than life science. The average correct-response rate for students for the combined physical science MOSART surveys was 43% and 58% for life science. The correct-response percentage per question for teachers participating during the instrument validation was not documented in the literature. Given that teachers carry similar misconceptions as their students (Burgoon et al., 2011), the physical science MOSART questions may inherently be more difficult for teachers than life science. For this reason, it is important that the questions first align with state teaching standards to demonstrate how teacher SMK measures relative to expected teaching standards, rather than prioritizing questions selection by difficulty.

Second, given that each subject area of my survey will include 10 questions, I selected about half of the ten questions from the K-4 survey and half from the 5-8 survey. The physical science section has five questions taken from K-4 survey and five questions taken from 5-8 survey. However, life science had more questions that fit the standards in the 5-8 survey than K-4, and thus six questions came from the 5-8 MOSART survey and four questions from the K-4 MOSART survey.
Third, to avoid difficulty bias, I selected the question based on difficulty according to the correct-response rate of students when Sadler, Coyle, et al. (2013) initially tested MOSART surveys with students as reported in the literature (the authors of the original MOSART did not report all the teacher correct-response percentage per question). I selected questions typically between 20-80% in terms of correct-response percentage while trying to balance the difficulty (Table 1). Mostly, the goal was to select questions so that the average correct-response percentage of students for life and physical science was close to each other or the averages of the original MOSART survey. The selection used for this survey has a student correct-response percentage mean of 37% for PS and 49% for LS. This difference in student correct-response percentage means is smaller than the difference in means between LS and PS of the original MOSART.

Last,

**Table 1**

*Subject Matter Knowledge Question Selection Summary*

<table>
<thead>
<tr>
<th>Question</th>
<th>Life science</th>
<th>Physical science</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MOSART instrument version</td>
<td>Original MOSART correct-response rate (%)</td>
</tr>
<tr>
<td>1</td>
<td>K-4</td>
<td>59</td>
</tr>
<tr>
<td>2</td>
<td>K-4</td>
<td>84</td>
</tr>
<tr>
<td>3</td>
<td>K-4</td>
<td>70</td>
</tr>
<tr>
<td>4</td>
<td>K-4</td>
<td>35</td>
</tr>
<tr>
<td>5</td>
<td>5-8</td>
<td>53</td>
</tr>
<tr>
<td>6</td>
<td>5-8</td>
<td>43</td>
</tr>
<tr>
<td>7</td>
<td>5-8</td>
<td>42</td>
</tr>
<tr>
<td>8</td>
<td>5-8</td>
<td>54</td>
</tr>
<tr>
<td>9</td>
<td>K-4</td>
<td>66</td>
</tr>
<tr>
<td>10</td>
<td>5-8</td>
<td>50</td>
</tr>
</tbody>
</table>
the four other researchers reviewed the draft of questions for difficulty balance, topic coverage, alignment to standards, and whether there were duplicate concepts. I finalized the survey questions once all reviewing researchers agreed on each criterion. See Appendix B for SMK survey questions.

This study used a multiple-answer concept inventory survey that involves content across different concepts within the current NGSS teaching standards. Using a multiple-answer concept inventory survey offered new insight than previous studies examining the association between teacher efficacy and knowledge because the questions allowed more potential for common misconception answers to be selected. In other words, answer selections for each question include distractors that target common specific student and teacher-held misconceptions tied to the teaching standards. For example, question 5 on the physical science SMK survey asks how a person can see a tree based on what the visible light waves are doing. Some answers suggest common student and teacher misconceptions that light comes from the eye to see the tree. Other answer choices target another misconception that light only needs to come into her eye directly from the sun to see the object, rather than the correct answer of the light needing to come from the sun and reflect off the object before reaching her eye. This type of questioning provides a more accurate measure of what the teacher actually knows when compared with other types of closed-ended questions, such as true or false questions used in similar studies (see Catalano et al., 2019).

The online survey includes a component to measure the participants’ discipline-specific STE using the Science Teaching Efficacy Belief Instrument (STEBI-A) for in-
service teachers (Riggs & Enochs, 1989). Riggs and Enoch reported a Cronbach’s alpha score of .76 for internal consistency reliability. Furthermore, a factor analysis found two discrete factors. The first subscale factor is Personal Science Teaching Efficacy Belief (PSTE), with an eigenvalue of 6.26, accounting for 25.0 percent of the variance. The PSTE subscale measures the teacher’s belief in their ability to teach students science knowledge and skills effectively. The second subscale factor is Science Teaching Outcome Expectancy (STOE), with an eigenvalue of 2.71 accounting for 10.8 percent of the variance. The STOE subscale measures the teacher’s belief of how much the student’s learning results from the teacher’s ability to overcome external factors. Survey items that load onto PSTE include numbers 2, 3, 5, 6, 8, 12, 17, 18, 19, 21, 22, 23, and 24. Survey items that load onto the STOE factor include numbers 1, 4, 7, 9, 10, 11, 13, 14, 15, 16, 20, and 25 (Riggs & Enochs, 1989).

To develop new discipline-specific teaching efficacy measures, I adapted STEBI to target “life science” and “physical science” beliefs separately rather than science as a whole. Instead of the survey reading the word “science,” I replaced each word “science” with either the phrase “physical science” or “life science” (see Appendix C for physical science STEBI). In this way, this study can measure disciplinary STE. For example, item five on the STEBI-A instrument reads, “I know the steps necessary to teach science concepts effectively.” I changed this sentence to “I know the steps necessary to teach physical science concepts effectively” and “I know the steps necessary to teach life science concepts effectively.” Items dealing with life science stayed in the same survey item order. However, they followed the online survey’s life science SMK test portion,
with physical science mirroring this survey sequence. In addition, life science and physical science were defined for each participant at the beginning of each section of the survey by also listing the related topics found within their science teaching standards document. Lastly, the study computed Cronbach’s alpha to ensure those scale items were internally consistent. The life science STEBI Cronbach alpha is 0.84, with the physical science STEBI alpha as 0.83.

The STEBI-A instrument uses a five-point Likert scale for each item. Thus, the science teacher efficacy scores are ordinal. This study treats these scores as continuous data for regression analysis (Norman, 2010). In addition, I determined SMK scores by summing the number of correctly answered questions. Thus, these SMK scores are also continuous.

**Quantitative Data Analysis**

Quantitative data from surveys were analyzed using R Studio. To answer the first question, I used a hierarchical regression analysis strategy to add various predictors to the model with several steps for each model. A total of four linear models were computed separately (see regression models below). The dependent variable of each model is personal teaching efficacy and science teaching outcome expectancy for each discipline. The independent variables (predictors) are life science SMK and physical science SMK. Given that years of teaching experience can affect SMK (Nixon et al., 2019) and self-efficacy (Tschannen-Moran & Hoy, 2007), the model accounts for possible covariates such as years of teaching experience. Given that disciplinary SMK can differ between grade levels because each grade has different teaching standards, I included the two grade
levels 4th and 5th, coded as binary, as a possible covariate (Utah State Board of Education, 2019).

A test for interaction was included in the models to measure any potential effects that the SMK of one discipline might have on another discipline’s STE. If a significant interaction existed, this would suggest that when discipline-specific SMK category changes, there would be an effect on overall STE affecting both physical and life science STE. However, this was not the case. The study’s regression models are as follows:

\[
\hat{PSTE}_{LS} = \beta_0 + \beta_1 (SMK)_{LS} + \beta_2 (SMK)_{PS} + \beta_3 (SMK)_{PS}(SMK)_{LS} + \beta_4 (years) + \beta_5 (grade)
\]

\[
\hat{PSTE}_{PS} = \beta_0 + \beta_1 (SMK)_{LS} + \beta_2 (SMK)_{PS} + \beta_3 (SMK)_{PS}(SMK)_{LS} + \beta_4 (years) + \beta_5 (grade)
\]

\[
\hat{STOE}_{LS} = \beta_0 + \beta_1 (SMK)_{LS} + \beta_2 (SMK)_{PS} + \beta_3 (SMK)_{PS}(SMK)_{LS} + \beta_4 (years) + \beta_5 (grade)
\]

\[
\hat{STOE}_{PS} = \beta_0 + \beta_1 (SMK)_{LS} + \beta_2 (SMK)_{PS} + \beta_3 (SMK)_{PS}(SMK)_{LS} + \beta_4 (years) + \beta_5 (grade)
\]

where LS is life science, PS is physical science, SMK is SMK, PSTE is personal science teaching efficacy, STOE is science teaching outcome expectancy, and \( \beta \) is a regression coefficient.

In all, I compared the effect of SMK on STE (both subscales) between life and physical science. Factors that likely influence the effect of SMK on STE, such as teacher grade level, or school, were accounted for in each model. Results from the SMK, PSTE, and LSTE scores were used to determine selected interviewees for phase 2 using the
criteria outlined in phase 2.

**Crosscutting Concepts and Correlation Between Items**

Energy, as declared by *A Framework for K-12 Science Education*, is a crosscutting concept. This means that energy is helpful as a lens or mental tool to understand other scientific concepts and naturally occurring phenomena across the science disciplines. Content knowledge has been measured for this study using MOSART survey items with a question in both life science (item 10) and physical science (item 6) that pertains to a concept of energy (see Appendix B). The life science question depicts a picture of the sun, grass, deer, and wolf in a food chain, then asks what energy would be available to the wolf. The question seeks to assess an understanding of how energy flows in ecosystems. The idea is that in food chains, some energy gets used by each organism in the chain. This concept is often taught when teaching about food chains, without the need for a full physical science understanding of how one would calculate energy loss or energy transfer. The physical science survey item asks about a portable electronic device that plays sound to recharge the batteries, thereby converting sound energy back into electrical energy. This question measures knowledge about energy conservation and the transfer of energy between forms of energy. Although similar to the life science question in that it deals with energy transfer, the physical science question additionally assesses the concept that no energy transfer is 100% efficient. In contrast, the life science energy question used a biological context where the learner may attribute the energy to food. That food gets used up as an animal engages in an activity. In other words, a life science
student could understand this context with little physical science background knowledge as it is but a small domain of the concept of energy.

This study does not measure crosscutting concepts within or across the SMK survey items. Each SMK item intends to measure discipline-specific knowledge domains across the standards most relevant to the teachers. For example, life science may include energy-related questions that can be understood and answered using the life science lens and not a physical science lens. Nonetheless, those teachers with a deeper understanding of energy may find the question understood in other deeper or more meaningful ways than just that of a life science context. The questions are not designed to do this. Instead, they are snapshots of domain-specific knowledge. To truly assess the crosscutting concept nature of knowledge (how concepts intersect across domains of knowledge), a broader and greater number of survey items around the concepts in question would need to be used.

To entertain a question about whether the energy knowledge measured in these two items had any statistical effect on other items in the survey, I recalculated the correlation of the life and physical science SMK surveys without the energy items. The correlation coefficient, without the energy items, increased from 0.16 to 0.20 while still showing statistical significance ($p = .01$). If knowledge about energy for this domain influenced other items, one might assume the correlation to increase when included in the correlation and decrease when removed from the survey. Instead, the analysis shows the opposite effect. Thus, it is unlikely that these energy questions assessed crosscutting concept knowledge that influenced that response to other survey items.
Phase 2

RQ 2: In what ways do teachers’ self-efficacy beliefs related to physical science knowledge, life science knowledge, and science pedagogy relate to their understandings of their classroom practices?

Interviews often best measure beliefs towards content knowledge (Jones & Carter, 2007). Self-reporting through interview questions provides a window into teachers’ perceptions of where they believe they have developed their confidence in teaching science subjects. Moreover, their responses reveal whether they are aware of potential sources of their discipline-specific science efficacy beliefs. Lastly, their accounts illuminate valuable information regarding connections between their efficacy beliefs and classroom practices.

Analysis of Qualitative Data

To better unpack the relationships between teacher SMK and teacher beliefs towards teaching specific science content, a purposeful sample of 11 teachers with varied SMK and efficacy survey scores was selected using each of the four categories (low efficacy/low SMK, high efficacy/low SMK, low efficacy/high SMK, and high efficacy/high SMK) to explore the nuances of differences identified. At the time of the survey phase, there was not yet data on mean scores for the survey because the questions originated from multiple validated MOSART instruments rather than a single MOSART survey. I developed this new survey to align with NGSS and state standards. Therefore, the selection criteria for high and low SMK are according to the relative scores between
teachers. The top tertile is regarded as “high” SMK, and the bottom tertile will be “low.” These same selection criteria were applied to the STEBI instrument, given that no mean score exists across the literature for the discipline-specific version of STEBI-A.

A participant qualified for “High SMK” if at least life or physical science SMK scores were in the top third of the entire group. Again, selection preference was given to those with high scores in both disciplines. A participant qualified for “High STE” if at least one of the survey subscales fell within the top third of scores for life and physical science. Again, preference was given to participants with high scores across all subscales and disciplines. Likewise, “Low SMK: and “Low STE” followed the same criteria rules but for the bottom third of all scores.

Following the online survey, 25 participants met the interview criteria. Of those, I interviewed 11 voluntary survey participants: three qualified in the High SMK/High STE group, two in the Low SMK/ High STE group, two in the High SMK/ Low STE group, and three in the Low SMK/Low STE group.

The interview questions sought to understand what aspects of physical or life science teachers are most or least confident in and where they may have developed such beliefs. In addition, other interview questions sought to understand how the participants teach each science discipline and what differences in practice might emerge because of their efficacy beliefs. Appendix D provides the interview questions.

This study used a systematic coding process that involved a combination of deductive and inductive coding strategies. To facilitate the first deductive coding cycle, I derived codes from the theoretical framework and the literature review around STE and
SMK. Accordingly, I established the first cycle codes for each discipline as High and Low STE and High and Low SMK (see Table 7 in the Results section). These codes were derived as follows. The literature on STE suggests that teachers with low STE believe they use ineffective science teaching methods, lack the ability to teach science effectively, or have low confidence in their ability to explain specific science concepts. (Bandura, 1977; Hoy et al., 2009; Riggs & Enochs, 1989). Therefore, we assigned the code Low STE for each discipline using these criteria, with High STE being the opposite. Given that some interview questions were based on the PSTE items of Riggs and Enoch’s (1989) STEBI-A instrument, the coders also used the item descriptions to guide their codes being either Low or High Efficacy based on the responses to these questions. For example, the interview questions that ask teachers to identify which science topics they believe they teach effectively (or ineffectively) and why is based on STEBI-A items 5, 8, and 12, which assess teachers’ beliefs about their science teaching effectiveness and their knowledge of effective science teaching practices, and whether they understand science concepts enough to explain them. When coding for High and Low SMK, coders identified interview segments that illustrated a teacher’s belief about their own knowledge of various topics across life and physical science. These coded segments reflect self-reports of the teacher’s own knowledge rather than an assessment of their actual understanding of the concepts.

These derived codes also categorize interview data to help explain this study’s statistical results while contrasting them with the literature’s claims for general STE. A strength of deductive coding is that it is a systematic approach to using known categories
of codes to help explain some of the quantitative result patterns (C. Marshall et al., 2022). For example, the theoretical framework suggests that content knowledge influences teachers’ efficacy in teaching domain-specific content (Bandura, 1977; Palmer, 2011; Tschannen-Moran & Hoy, 2001). Participants in this study were categorized into four categories based on their science knowledge and teaching efficacy survey results. According to SCT, teachers who measured high in their science SMK survey results would be expected to report high STE in their interviews. Coding teachers’ interview responses using the same codes as their survey score categories allows us to investigate their self-awareness of efficacy and knowledge, the relationship between the two within each discipline, and whether there are nuanced differences between disciplines. Moreover, according to the literature, teachers who exhibit high STE would be expected to report practices that align with high efficacy such as teaching science regularly, using more science inquiry methods, and relying less on scripted lesson procedures than those with low STE (Harlen & Holroyd, 1997; Hoy et al., 2009).

Rather than limit the literature-derived codes to explain statistical results, I developed codes from emergent patterns around beliefs and practices teachers exhibited within and across the categories of the first codes to help explain the quantitative statistical results from lesser-known themes. In this way, novel patterns in teachers’ instructional methods or their beliefs about teaching and learning science could emerge. For example, it was unexpected that teachers’ lesson descriptions would focus mainly on teachers’ actions or students’ actions in addition to where elementary teachers placed the responsibility for students’ science learning challenges. These emergent codes (inductive
coding) further explained survey findings in more nuanced and novel ways (see Table 8 in the Results section).

**Interview Data Validity**

I cross-checked interview questions with another education researcher for leading questions, word usage, bias, and errors. In addition, I also tested the interview questions with four elementary teachers, who are not participants in this study, to understand how teachers respond to the questions and how much time each question would take to answer.

Interviews took place via Zoom’s online video conferencing software. Researchers transcribed teacher interviews and developed codes using theory-driven coding strategies to begin, followed by emergent coding methods (C. Marshall et al., 2022). Three researchers, two coders and one code verifier, analyzed the interview data. The first coding round was to establish consensus with codes and code definitions. This coding round was done with one researcher developing codes and code definitions and another acting as a code-verifier to examine the saliency of codes and to cross-check for consistency and validity. Once code definitions were agreed upon, a third coder was brought in to systematically and independently code the data using definitions agreed upon by the first coder and code verifier. The two independent coders met to systematically compare differences and mutually revise initial claims. The coders reached a consensus by meeting their initial 90% interrater agreement target. This study only uses coded segments of interview data that were agreed upon by both coders. Themes were developed from within-case and across-case approaches. A cross-thematic analysis
followed. I provide a further detailed discussion on how codes were created and defined in Chapter IV.

**Mixing Quantitative and Qualitative Data**

Integrating the qualitative findings with quantitative results involved using the themes found from the code analysis and making connections to the statistical results. During this phase, questions addressed include: What themes help explain the differences in STE and SMK between the disciplines? Are there any unexplained themes that have no connection with the statistical results? Are there qualitative findings that help explain non-significant results? Which aspects of the thematic findings can help explain significant factors of STE? Do the thematic findings demonstrate trends or patterns between the interviewee category groupings? Last, can the qualitative results explain any outlier results or confusing findings from the quantitative analysis?
CHAPTER IV
RESULTS

As described in Chapter I, this study focuses on understanding the relationship between elementary teachers’ SMK and STE in life and physical science. Furthermore, the study examines elementary teachers’ beliefs regarding their life science and physical science instruction as articulated by the teacher.

This chapter reports on the findings that answer each research question sequentially, as laid out in the methodological approach found in Chapter III. First, I report the relationship between SMK and the STEBI instrument’s two subscales: personal science teaching efficacy (PSTE) and science teaching outcome expectancy (STOE), as they relate to life and physical science. Next, I describe this relationship by reporting the statistical results from online survey data by applying hierarchal regression analysis and paired t tests. The second part of this chapter focuses on the qualitative findings around the teachers’ articulated beliefs about their life and physical science instruction. Additionally, the qualitative results will be integrated with the quantitative results to demonstrate the explanatory power of the interview findings as they relate to the quantitative results.

Phase 1 – Quantitative Survey Results

This study sought to understand if the following linear regression models are statistically significant, and if not, which models are statistically significant given the measured predictors.
Using hierarchal linear regression analysis, physical science subject matter knowledge (PSSMK) combined with life science subject matter knowledge (LSSMK) are statistically significant predictors of physical science personal science teaching efficacy (PSPSTE) when accounting for life science subject matter knowledge (LSSMK), years of teaching, and grade level; $R^2 = 0.05$, $p = .04$ (see Model C in Table 2). Additionally, PSSMK is a statistically significant predictor of life science personal science teaching efficacy (LSPSTE) when accounting for life science subject matter knowledge (LSSMK), years of teaching, and grade level; $R^2 = 0.03$, $p = .04$ (see Model C in Table 3).

While PSSMK was measured to be a statistically significant predictor of LSPSTE when controlling for LSSMK, years of teaching, and grade level ($R^2 = .03$, $p = .04$), LSSMK was not. Therefore, a teacher’s knowledge of life science is not a significant factor in their efficacy towards how confident the teacher believes they are in teaching life science, but physical science subject matter knowledge is.

Other regression models that examined SMK effect on life science teaching
Table 2

Hierarchal Regression Results for Physical Science Personal Science Teaching Efficacy

<table>
<thead>
<tr>
<th>Variable</th>
<th>Model A</th>
<th>Model B</th>
<th>Model C</th>
<th>Model D</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>35.64 (3.78)**</td>
<td>35.75 (3.89)**</td>
<td>35.15 (3.94)**</td>
<td>30.70 (11.28)**</td>
</tr>
<tr>
<td>PSSMK</td>
<td>0.86 (0.38)*</td>
<td>0.85 (0.38)*</td>
<td>0.80 (0.39)*</td>
<td>1.75 (2.30)</td>
</tr>
<tr>
<td>LSSMK</td>
<td>0.89 (0.46)</td>
<td>0.90 (0.46)</td>
<td>0.92 (0.46)*</td>
<td>1.49 (1.44)</td>
</tr>
<tr>
<td>Years</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Grade Level (5)</td>
<td></td>
<td></td>
<td>1.27 (1.31)</td>
<td>1.34 (1.32)</td>
</tr>
<tr>
<td>PSSMK*LSSMK</td>
<td>-</td>
<td>-</td>
<td>-0.12 (0.29)</td>
<td></td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.06</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
</tr>
</tbody>
</table>

*Note. Standard errors are in parenthesis. Regression coefficients are raw unstandardized values. *$p < .05$. **$p < .01$. ***$p < .001$. 

outcome expectancy (LSTOE) and physical science teaching outcome expectancy (PSTOE) revealed no statistical significance for any of the measured possible factors. Thus, SMK in either discipline, years of teaching, or grade level, does not affect a teacher’s belief in their ability to change the student’s learning outcomes.
When examining the correlations between the measured variables (Table 4), there is a small, significant, and positive correlation between PSSMK and both physical science PSTE \( (r = 0.215, p = .01) \) as well as life science SMK \( (r = 0.193, p = .02) \). Similarly, there is a positive correlation between life science SMK and physical science PSTE \( (r = 0.193, p = .02) \). Additionally, there is a very small significant correlation between physical science SMK and life science SMK \( (r = 0.16, p = .05) \), suggesting that those who are highly knowledgeable in a subject area tend to be knowledgeable in the other subject area. Moreover, according to their survey responses, the more confident a teacher was in teaching life science, the more likely the teacher was also confident to teach physical science. This relationship is true for personal science teaching efficacy as it is a teacher’s outcome expectancy beliefs for life science and physics science, as seen by the significant correlations in Table 4 between each teaching efficacy measure.

**Table 4**

*Pearson Correlation Coefficients Between All Survey Items*

<table>
<thead>
<tr>
<th>Variable</th>
<th>PSSMK</th>
<th>LSSMK</th>
<th>LSPSTE</th>
<th>PSSTE</th>
<th>LSTOE</th>
<th>PSTOE</th>
<th>Years</th>
<th>Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSSMK</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LSSMK</td>
<td>0.163*</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LSPSTE</td>
<td>0.193*</td>
<td>0.145</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PSPSTE</td>
<td>0.215**</td>
<td>0.193*</td>
<td>0.835**</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LSTOE</td>
<td>0.081</td>
<td>-0.019</td>
<td>0.191*</td>
<td>0.206*</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PSTOE</td>
<td>0.08</td>
<td>-0.011</td>
<td>0.181*</td>
<td>0.208*</td>
<td>0.988**</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Years</td>
<td>-0.051</td>
<td>0.046</td>
<td>-0.073</td>
<td>-0.012</td>
<td>0.023</td>
<td>0.025</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>Grade</td>
<td>0.137</td>
<td>-0.034</td>
<td>-0.027</td>
<td>0.099</td>
<td>0.061</td>
<td>0.055</td>
<td>0.042</td>
<td>1.00</td>
</tr>
</tbody>
</table>

*\( p < .05 \). **\( p < .01 \). ***\( p < .001 \).
This study found no statistically significant correlations between a teacher’s SMK and teaching years for physical and life science. There were also no statistically significant correlations between a teacher’s STE and years of teaching for both physical and life sciences. Thus, an increase in years of teaching experience does not, on average, indicate that the teacher’s SMK or STE will increase. This lack of correlation between SMK or STE and years of teaching was only observed across the teacher’s entire career teaching years as reported, not at segmented intervals across the teaching cycle. This study also found no statistically significant correlations between grade level and SMK, PSTE, or STOE.

This study used two-tailed paired $t$ tests to evaluate the mean differences between life science and physical science regarding SMK and STE (Table 5). Cohen’s $d_z$ is used in this analysis for the effect size given that the study uses a within-subject design and therefore justifies using the standard deviation of the mean differences as the standardizer in calculating the effect size (Lakens, 2013). There is a statistically significant difference between PSSMK ($M = 5.0, SD = 1.7$) and LSSMK ($M = 7.7, SD = 1.4$), with LSSMK being 2.7 points higher than PSSMK and a very large standardized mean difference of $d_z = 1.34, t(138) = 15.5, p < .001$ (two-tailed). The common language (CL) effect size indicates that after controlling for individual differences, the likelihood that a person scores higher for life science SMK than for physical science SMK is 91% (Lakens, 2013).

Additionally, there is a statistically significant difference between physical science PSTE ($M = 46.8, SD = 7.7$) and life science PSTE ($M = 47.7, SD = 7.5$), with life
Table 5

Mean Differences Between Life Science and Physical Science

<table>
<thead>
<tr>
<th>Measure</th>
<th>Life science</th>
<th>Physical science</th>
<th>Mean diff</th>
<th>Cohen’s $d_z$</th>
<th>Paired t test</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMK</td>
<td>7.7 1.4</td>
<td>5.0 1.7</td>
<td>2.7</td>
<td>1.34</td>
<td>t(138) = 15.5, p &lt; .001</td>
</tr>
<tr>
<td>PSTE</td>
<td>47.7 7.5</td>
<td>46.8 7.7</td>
<td>0.9</td>
<td>0.21</td>
<td>t(138) = 2.4, p = .020</td>
</tr>
<tr>
<td>STOE</td>
<td>41.7 5.4</td>
<td>41.9 5.3</td>
<td>0.2</td>
<td>0.24</td>
<td>t(138) = 2.6, p = .010</td>
</tr>
</tbody>
</table>

science PSTE being 0.9 points higher than physical science PSTE on the adapted STEBI-A instrument, yielding a small standardized mean difference of $d_z = 0.21$, $t(138) = 6.9$, $p < .001$ (two-tailed). The CL effect size shows that after controlling for individual differences, there is a 58% likelihood that a teacher participant scores higher for physical science PSTE than life science PSTE.

However, a comparison of mean differences of STOE for each subject area demonstrates a statistically significant difference between life STOE ($M = 41.7$, $SD = 5.4$) and physical STOE ($M = 41.9$, $SD = 5.3$), bearing a small standardized mean difference of $d_z = 0.22$, $t(138) = 2.6$, $p = .01$ (two-tailed). In this latter statistic, the mean for LSTOE is larger than the mean for PSTOE. The CL effect size indicates that after controlling for individual differences, the likelihood that a person scores higher for life science STOE than for physical science STOE is 59%.

These differences indicate that the teachers are more knowledgeable and confident in their personal ability to teach life science topics than they are physical science topics. These differences are also apparent in the follow-up interviews, where eight of the eleven participants reported physical science topics as their least effective
teaching topics. The only teachers who did not report a physical science topic as something they felt less confident teaching were the three interviewed participants who scored in the top tertile of SMK and an STE category for both science disciplines. Nonetheless, the survey participants’ confidence in influencing student learning outcomes (STOE) is higher for physical science than for life science, as shown in Table 5.

**Phase 2 – Qualitative Survey Results**

Following the online surveys, the purpose of interviewing a select group of survey participants was to explore how teachers articulated their understandings regarding life and physical science instructional choices, SMK, and teaching efficacy beliefs. Furthermore, this study also seeks to understand how teachers describe the source of their beliefs concerning their efficacy and content knowledge.

I selected follow-up interview participants using four qualifying criteria categories: (1) high SMK/high STE, (2) high SMK/low STE, (3) low SMK/high STE, and (4) low SMK/low STE. These criteria are applied to the selection to understand how nuanced levels of SMK or STE influence a teacher’s classroom instructional decisions and beliefs. Furthermore, in having various categories of high and low SMK or STE, the analysis is more likely to reveal how a change in a single SMK or STE category influences a teacher’s classroom practice and pedagogical beliefs. Finally, this type of analysis affords the use of qualitative findings to support any quantitative results or to reveal other possible outcomes that may not align with the quantitative results.

A teacher who scored in the top tertile for their SMK survey for both physical and
life science is considered “High SMK.” Similarly, “High STE” is characterized as those teachers in the top tertile with both a physical and life science score of at least one of the two measured factors (PSTE or STOE) of the adapted Science Teaching and Beliefs Instrument. I categorized the “Low SMK” and “Low STE” as those who scored in the bottom tertile of survey scores. Of the 139 survey participants, 25 qualified under the criteria mentioned earlier. Eleven of those 25 qualified participants responded to the invitation to be interviewed by zoom. Three teacher participants qualified in the High SMK/High STE category, two in the Low SMK/High STE category, two in the High SMK/Low STE category, and four in the Low SMK/Low STE category. Table 6 shows these participants in their respective categories using pseudonyms to protect the identity of participants.

Table 6

Teacher Participant Demographics by Category

<table>
<thead>
<tr>
<th>Low SMK/Low STE</th>
<th>Low SMK/High STE</th>
<th>High SMK/Low STE</th>
<th>High SMK/High STE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teacher</td>
<td># years teaching</td>
<td>Grade</td>
<td>Teacher</td>
</tr>
<tr>
<td>Kimmy</td>
<td>16</td>
<td>4th</td>
<td>Camila</td>
</tr>
<tr>
<td>Erin</td>
<td>4</td>
<td>4th</td>
<td>Jessica</td>
</tr>
<tr>
<td>Ashton</td>
<td>5</td>
<td>4th</td>
<td></td>
</tr>
<tr>
<td>Ally</td>
<td>24</td>
<td>4th</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Leah</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Hannah</td>
</tr>
</tbody>
</table>

Among those in the Low SMK/Low STE group are Kimmy, Erin, Ashton, and Ally. Kimmy, who has been teaching for 16 years, currently teaches fifth grade at a Title I school that serves about 600 students within a suburban school district. Erin is in her fourth year of teaching, having taught both fourth and fifth grade. She teaches in a school
that serves about 550 students from a school district that is situated in a large suburban setting. Ashton currently teaches fourth-grade students through an online school for the past two years. She taught fourth grade in-person classes 3 years prior. The online school is part of a suburban school district. Ally is a fourth-grade teacher in her 25th year of teaching. She teaches at a Title I school that serves about 450 students in a suburban setting.

The Low SMK/Low STE group includes Camila and Jessica. Camila has taught for 5 years as a fourth-grade teacher in Title 1 school that serves about 350 students. The school is located in a large suburban area. Jessica is also a fourth-grade teacher at a school that serves about 500 students in a large suburban district. She is in her seventh year of teaching.

The High SMK/Low STE group includes Karina and Rosalina. Karina is a fifth-grade teacher, in her 24th year of teaching. Karina teaches at a school the serves about 560 students from a large suburban school district.

The High SML/High STE group includes Leah, Karalee, and Hannah. Leah is a fifth-grade teacher who has taught for 5 years. She teaches in a Title 1 school of about 250 students from a rural school district. Karalee is a fifth-grade teacher who has a graduate degree, STEM endorsement, and has taught for 20 years. She currently teaches in an urban school district at a school that serves about 500 students. Hannah is a fourth-grade teacher in her 13th year of teaching. She has a STEM endorsement and teaches in a Title 1 school that serves about 700 students located in a large suburban area.
Theory-Driven Codes (First Cycle)

The transcribed interviews were read through using theory-generated codes to understand how the qualitative findings relate back to the initial quantitative results and to develop a sense of the emerging themes (C. Marshall et al., 2022). Specifically, these initial codes were developed around how teachers described their effectiveness in teaching either life or physical science (high and low efficacy) and what they communicated about their background knowledge in life and physical science (high and low SMK). A second cycle of emergent codes was then distilled from both likely themes from the literature and shared characteristics found within the transcript data across various groups of participants. Tables 7 and 8 (shown and discussed later in this chapter) show the codes, definitions, and examples of each.

This study used this coding analysis to understand if the teachers knew their own knowledge and teaching efficacy levels, how their beliefs might explain the quantitative findings, and what they attributed to the source of those beliefs. I based most initial codes on participants’ direct responses to the interviewer’s questions. Details about each code are as follows.

High and Low STE

Of the segments coded with a high or low SMK in either subject area, all but two were a direct answer to the question asking about the teacher’s confidence or effectiveness at teaching a science topic. For example, when the interviewer asked which topics the teacher felt they could most effectively teach, teachers responded with either a physical or life science topic. Similarly, the interviewer asked about the most ineffective
### Table 7

**Theory-Driven Codes (First Cycle) with Examples**

<table>
<thead>
<tr>
<th>Initial codes</th>
<th>Definition</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Physical STE</td>
<td>Demonstrating high confidence in their (teacher) ability to effectively teach students a physical science topic or concept.</td>
<td><em>Hannah:</em> “I feel pretty confident about energy. So yeah, probably the energy ones I feel the most confident in. The whole strand is really fun. Overall, I think I may be more of a physical science person. And so, since it’s very energy, physical science heavy, I like that a lot.”</td>
</tr>
<tr>
<td>Low Physical STE</td>
<td>Demonstrating low confidence in their (teacher) ability to effectively teach students a physical science topic or concept.</td>
<td><em>Jessica:</em> “That could be because I’m not a good teacher at [energy], but I think energy’s complex for fourth graders.”</td>
</tr>
<tr>
<td>High Life STE</td>
<td>Demonstrating high confidence in their (teacher) ability to effectively teach students a life science topic or concept.</td>
<td><em>Ashton:</em> “Geology has always been interesting to me, and my grandpa was a geologist. So, I feel pretty confident in talking about the fossils and the layers of the earth and stuff like that.”</td>
</tr>
</tbody>
</table>
| Low Life STE      | Demonstrating low confidence in their (teacher) ability to effectively teach students a life science topic or concept. | *Interviewer:* “Which strand, or topic, do you feel least effective at teaching?”

*Hannah:* “I guess just the fossil thing because I don’t have enough examples.”

| High PSSMK        | Discussing their knowledge in a way that demonstrates they understand content, or believe they have strong background knowledge, of a physical science topic or concept. | *Ally:* “I feel like I maybe knew a little bit more about energy, could put a little bit more hands on, good experiments for the kids versus, the first one, the organisms, all that was really tough at first.” |
| Low PSSMK         | Discussing their knowledge in a way that demonstrates they don’t understand content, or believe they have weak background knowledge, of a physical science topic or concept. | *Interviewer:* “Which topics do you know the least about?”

*Ashton:* “It’d be those energy units, the collisions and all of that.”

| High LSSMK        | Discussing their knowledge in a way that demonstrates they understand content, or they believe they have strong background knowledge, of a life science topic or concept. | *Interviewer:* “So out of the topics then, what topics do you feel like you know the most about?”

*Erin:* “I would say the organism one.”

| Low LSSMK         | Discussing their knowledge in a way that demonstrates they don’t understand content, or they believe they have weak background knowledge, of a life science topic or concept. | *Ally:* “Yes. Reading through the standards document was hard. Like the first time, or like, what are these, what are they talking about? Like with these organisms? And it was really tough for all of us too, cause I guess the science, maybe this is science.” |
topic they teach. In addition, teachers sometimes brought up their confidence in teaching a topic well when discussing their background connections with the topic, as Ashton had done when she described her experience growing up with a liking for fossils within.

Geology has always been interesting to me, and my grandpa was a geologist. So, I feel pretty confident in talking about the fossils and the layers of the earth and stuff like that.

Fossils within the fourth-grade standards are identified by NGSS as a life science topic because they are used to explain environments and how living things change over time. Therefore, I coded this segment as “High Life Science Teaching Efficacy.” In addition, some teachers’ background with science coursework and identifying with science helped shape their confidence to learn and teach science, as had happened with Hannah in her response.

Hannah: I really enjoy the energy one. The whole strand is really fun. We’re doing waves right now. That’s a lot of fun. My kids are loving science. They just really get into it. Overall, I think I may be more of a physical science person. And so since it’s very energy, physical science-heavy, I like that a lot.

Interviewer: What makes you a physical science person? Why do you see yourself as a physical science person?

Hannah: Well, I did my STEM endorsement, and so we did a class in each area. We did a chemistry class. I don’t know if we did biology. We did geology. And oh yeah, we did one. It was about urban ecology, so I guess that’s more the biology class. But my physics teacher was just amazing. He was so good, and we’re still friends today. And it’s just really fun. And one thing I really love teaching about physics is that it’s very easy to make things hands on and very interactive with the kids, especially with the ones we have, like object sliding. That’s really simple. That’s a really easy way to do that, really actually do it in the class, as opposed to... This isn’t a bad thing, but ecosystems, you can’t bring a tundra into the class. It’s more very active.

Hannah had a lot of coursework in physical science in college and identifies with
physical science more than life science. Additionally, she talks about how easy it is to teach energy and waves concepts to her students and how “they get into it.” Therefore, I coded this segment as “High Physical Science Teaching Efficacy.”

*High and Low SMK*

About half of the segments coded as high or low SMK in life or physical science were in response to a question about which topics the teachers felt they knew most or least. The other half of coded comments mostly came from teachers explaining why they felt they were effective or less effective at teaching one topic over another. As an example, Erin reasons about her reasons she thinks she is ineffective in teaching about waves because she “doesn’t have too much background knowledge on it and had to go study it.” Similarly, Kimmy asserts that her background limited her ability to teach earth science effectively, saying:

I don’t have a good science background myself. I went to school in California. I’ve only been teaching, well only 17 years. It’s a long time. But in California you did not get a teacher education degree. You got a degree in whatever. Then went back for a year and they taught you how to be a teacher. Really the only science I had in college, and that was as an adult. I wish I were better prepared in college to teach science.

Kimmy’s response is a demonstration of low physical SMK. Other teachers also attributed their background college or life experiences as reasons they do not know much about science. For example, Leah describes why she felt less adequately prepared to teach about properties of matter compared to other science topics when she remarked:

I have absolutely zero chemistry background. I didn’t take any of those classes in school. Just lack of understanding.

Ashton also regarded her low background knowledge in energy because of her
lack of adequate teacher preparation in college, saying, “I didn’t remember learning about it in school myself.” Ashton, Leah, Kimmy, and Erin’s responses are examples of low physical science SMK.

On the other hand, some teachers identified with science and articulated beliefs about themselves as “science people” by focusing on prior experiences, as Hannah says:

Well, I did my STEM endorsement, and so we did a class in each area. We did a chemistry class. I don’t know if we did biology. We did geology. But my physics teacher was just amazing. He was so good, and we’re still friends today. And it’s just really fun.

Leah similarly recalled her high background in life science stemming from classes in college, saying:

I love geology and I had a lot of geology classes in college. My first major was parks and recreation management. And I had a lot of geology classes in that. Just electives. When I had to have science credits, that’s what I always chose.

Hannah and Leah’s statement demonstrates the teacher’s extra coursework in science, with some classes going beyond the required teaching degree course load and thus coded as “High SMK.”

**Emergent (Second Cycle) Codes**

I completed a second read-through to apply pattern coding techniques to develop more nuanced codes around the types of lessons enacted, such as the themes of “teacher-centered” or “student-centered” lessons, “hands-on lessons,” and “scripted lessons.”

These common patterns emerged through the first reading and demonstrated the types of instructional and pedagogical decisions teachers made due to their efficacy beliefs and background knowledge.
Teacher-Centered and Student-Centered

Teachers described classroom activities and lessons in at least two distinct ways. First, some responses primarily focused on activities the students were engaged in (student-centered). The other descriptions of what was happening in the classroom focused more on what the teachers were doing (teacher-centered). Teacher-centered lessons, or classroom events, include classroom discussions led by the teacher. These teacher-described discussions tend to follow a dialogic approach where the teacher asks a question, the teacher listens to the student’s answer, and then the teacher evaluates the answer. However, teachers describe this dialogic enactment in terms of mostly what the teacher must do and say to their students. In these types of explanations, the teacher thinks about what they are doing to instruct and less about what the student is doing. As an example, Camila describes a life science lesson saying:

So, I showed them a video and the kids know is a phenomenon. For example, animal hunting another animal. And then we talk about what we observe. And then from then, I introduced a topic. And in this case, we talk about what structures does the animal have that helps him succeed in this video.

Similarly, Hannah also summarizes how she teaches about structures and functions of plants by saying:

Well, I just show a video or a picture and be... They pretty much know it. A lot of the times there’s always kids that knows. So, I show them a video or show them a picture of both of them, and like, “What do you notice about them?” Sometimes you don’t even need to show them in the habitat. Sometimes you can have them predict like, “What do you think? Where do you think they’d be living based on what you see about them?” Stuff like that.

Some teachers will describe in general terms what “we,” the class is doing, but they are describing what the teacher is saying and wants the students to know and be able to do.
For example, Leah describes her lesson on properties and changes of matter as what she tries to get her students to do and what she wants them to think or know. Rather than describing what the students are doing or how they are doing it, she focuses on what she is doing but phrases it as “we did this.” Leah states:

I know I started with the KWL chart. What do you know? What do you want to know? What did we learn? So, we started with the KWL chart as we talked about matter because most of the kids had already had a preliminary lesson in fourth grade. And so they knew that everything was made up of matter. And then we tried to talk about how tiny it was. So, we had a mentor text and we read a book that talked about this much would fit on the head of a needle or a head of a pen and all of that. I just to try to get them to wrap their head around how tiny particles of matter are.

On the other end of the spectrum are student-centered descriptions of lessons or classroom activities that primarily include what the students do in the classroom to learn the content. There is less focus on what the teacher is doing and more on what the student is doing. Student-centered activities include student discussions, experimentation, model development, data collection, data analysis, and asking questions. These are crucial science and engineering practices within the Next Generation Science Standards.

Some teachers described their lessons as hands-on experiments their students do. As an example, Leah describes a lesson on properties of matter as mostly what the students are doing and not just learning:

Each team had a tray of materials that I had prepared ahead of time. And then each team was assigned a property of matter. Is it reflective? Does it conduct electricity? Is it magnetic? And then each team conducted their experiments with the objects that they had and had to keep records, graph that on their table, which things were or were not had that property. And then we came back together for the last five minutes of class to discuss their different discoveries.
Scripted and Non-Scripted Lessons

Teachers also described the source of the curriculum when describing lessons. These lessons could be from the curriculum they adapted or modified over the years, something new they were trying that they developed, or a prescriptive lesson with step-by-step procedures and scripted presentations. When teachers described their reliance on these district- or online-provided lessons, procedures, and accompanying presentations, I coded their remarks as “Scripted Lesson.” Anything other than this I coded as “non-scripted.” The term scripted has historically been denoted as lesson materials in which curriculum developers provide teachers specific verbiage, or scripts, to read out loud to their students. However, for this code, I use “scripted” to primarily mean written procedures or scripted slide presentations that a teacher follows line by line rather than just exact verbiage text that teachers read aloud. An outside source develops these types of curriculum resources (e.g., district personnel, publisher, or website) rather than a curriculum created or modified by the teacher.

Some teachers reported following the structure of the plan or presentation to teach, as was the case with Camila, who claims, “I follow the same structure because that’s the one that we have in our manual. To show the phenomenon, to elicit questions. But it’s probably the one I feel less comfortable in knowledge.”

Several teachers also found district-provided presentations through Nearpod useful for instruction, student questions, and activities. Ally describes her lesson on energy as one that relied on the curriculum provided by the district. She states,

I also will go to the Canvas one that our district put in. That’s probably where I go to first and I’ll print that off and I’ll look and see what I need to teach. …
Nearpod is pretty good. Most of them are pretty good about going like online with things as far as the outline of it. So, we’d go through the Nearpod that has questions or activities about it. So, we would do that and either they would, what’s good about the Nearpod is they would now all be able to ask a question about like what does energy transfer mean? They’d all have to type in an answer, and I can see all their answers and see how they’re understanding it.

Ashton also describes her source of curriculum as coming from the district or from online. For example, she uses district videos and some from a YouTube show called SciShow Kids. For presentations, she says, “the district does have Nearpods that they’ve created, and so I do use those quite often, too.”

Other teachers reported using online resources that provide step-by-step guides for experiments, questions to ask, and presentations. One such teacher to use online sources for the curriculum was Kimmy as she explained how she taught about energy:

Mystery Science just came out with a step-by-step, and he’s got the patterns and I print the patterns and we’re able to make fun experiments. So on the energy transfer, I’ll be honest, I have literally used the Mystery Doug website. Let me just pull up. His first lesson talks about speed and energy and just energy, in general, and compares it to a car. How are our bodies like cars, that we kind of talked through that, but every living thing has some sort of energy. The next lesson was on collision and energy transfer. … It was really good at kind of walking it through. Then, because it’s Doug [from Mystery Doug website], he could summarize it up more intelligently than I could. This statement from Kimmy demonstrates her need to use an online source as a walkthrough in both procedures, instruction, and some student discussion questions. I coded this kind of activity as a “scripted lesson.”

When teachers did not convey or imply that they were using outside or district-provided sources for curriculum, I coded their lesson activities as “non-scripted lessons.” Some teachers described the need to find their own materials or adapt the instruction to meet the standard, as when Ashton describes her lesson on having students compare
organisms stating,

So, yeah. With that one, well, there was one lesson where they were supposed to compare modern-day organisms with the fossils that are similar to them. So, I just tried to find pictures of... I actually have a trilobite fossil, so I tried to find a picture of the modern day. I can’t remember now what that one’s called, but it lives in the ocean, the modern day one. And we compared and contrasted how those are similar and different. And I found other pictures, too, of fossils with their modern animals and compared and contrasted their structures and functions.

In a similar way that Ashton adapts to showing a fossil to the students through different pictures she found, others developed their own activities to meet the standard, as observed in Rosalina’s response about food chains in life science:

What I had done with those ones is for food chains, energy going through them, is trying to start with things with the decomposers, introduce the concept of how it can take matter, like leaf matter, grass matter, and these insects and other decomposers break it down and leave soil. And then start working the way up of, okay, this is, these are eaten by the birds and these birds are eaten and trying to make the way around and then back again. That was easy and at the same time it’s hard because I struggle with kids just doing book work for science. I hate book work for science, it’s so boring. And so when you’re just limited in resources, then it’s difficult to pull away from the bookwork for a lot of the concepts and the worksheets and whatnot. I would have tried to make a game, game cards where they had to match, make a food chain type thing, build up with that.

Another example of a teacher-developed activity is with Leah, who uses a “grow-table” in her classroom to grow various plants with students (see Table 7). She describes how she wants to try a new thing this year: filling a growing pumpkin with litter to see the effect while having her students then make observations. In these examples, neither Ashton, Rosalina, nor Leah discusses where they got their curriculum resources or describe their reliance on following a step-by-step guide to developing these activities.

As such, I coded these lesson descriptions as “non-scripted lessons.” Further examples and a list of these second cycle codes are in Table 8.
### Table 8

**Emergent Codes (Second Cycle) with Examples**

<table>
<thead>
<tr>
<th>Codes</th>
<th>Definition</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teacher-centered lesson</td>
<td>Lesson descriptions focused mostly on activities the teacher was engaged in, rather than what the students were doing. Sometimes teacher refers to the class as the disguised “we,” but interviewee typically doesn’t refer to students as “students,” “they/them,” or what students are engaged in doing apart from the teacher or whole class.</td>
<td><em>Camila:</em> So, I showed them a video and the kids know it’s a phenomenon. For example, animal hunting another animal. And then we talk about what we observe. And then from there, I introduce a topic. And in this case, we talk about the structures. What does the animal have that helps him succeed in this video?</td>
</tr>
<tr>
<td>Student-centered lesson</td>
<td>Lesson descriptions focused mostly on activities the students were engaged in, rather than what the teacher or whole class in general was doing. Description tends to describe more specifics of what the students are doing rather than just what “we” (the class) are doing.</td>
<td><em>Jessica:</em> We broke into groups and so they have their science groups and they got to work together to design a system with a pulley that would move a box from the ground to a tree house. And so, they were working with little VEX IQ kits and they just worked together to design it. And then on Friday we actually created their idea, their model, and they had to show me that they could move a little fake box from the ground to the top of a fake tree. And that was really fun. And then afterwards, we got together as the whole class and they filled out their Launch Logs, they answered their conclusion questions and that brought it all back together.</td>
</tr>
<tr>
<td>Hands-on experiments</td>
<td>Interviewee’s description of activities where students are engaging in an activity with hands-on manipulatives, or materials for experiments, rather than a discussion or worksheet.</td>
<td><em>Ally:</em> We had paper cups, metal cans, things with strings on them and they had a partner. So, they would try to hear and talk out of those for the sound transfer through this yarn. So then, we would do that activity with partners.</td>
</tr>
<tr>
<td>Scripted lesson</td>
<td>Description of the source of the curriculum when describing lessons. Scripted here means a prescriptive lesson with step-by-step procedures or scripted presentations. These descriptions describe a sort-of reliance on district- or online-provided lessons, procedures, and accompanying presentations.</td>
<td><em>Kimmy:</em> Mystery Science just came out with a step-by-step, and he’s got the patterns and I print the patterns and we’re able to make fun experiments. We made a roller coaster type of thing, where they talked about, how the energy transfers and height gives it the stored energy and so, that’s been really fun to do.</td>
</tr>
<tr>
<td>Non-scripted lesson</td>
<td>Descriptions of lessons that used curriculum the teacher adapted or modified over the years, or something new they were trying that they developed, instead of describing a reliance on lessons/activities provided to them from an online website or as a district-provided resource.</td>
<td><em>Leah:</em> I have a grow-table in my room. So, we always grow plants. That’s one of the things that we do. And we have, obviously, different variables with different plants. Some didn’t get watered; some didn’t get light. So that’s one of the things we did. One of the things that I’m going to do this year is take a pumpkin and they get to fill it with litter and we’re going to bury it. See what happens to it.</td>
</tr>
<tr>
<td>Science difficult because of student</td>
<td>Teacher demonstrates that students struggle in science because the student is incapable, or characteristics of students make science difficult.</td>
<td><em>Ashton:</em> Science is hard for students because “they are unable to transfer the knowledge to different situations.”</td>
</tr>
</tbody>
</table>

*(table continues)*
I used the codes from the first and second cycle rounds of coding to establish patterns of shared characteristics across each of the codes. One example of such patterns includes how teachers in the Low SMK/Low STE group described their lessons as teach-centered, whereas the High SMK/High STE group tended to depict their lessons as student-centered. More of these patterns are in Table 9. These patterned themes were then analyzed to answer the second research question of how teachers’ life and physical STE beliefs and knowledge related to their pedagogy and classroom practices.

**Findings from Themes Across All Groups**

The following findings from the thematic findings seek to answer the second research question. Table 9 summarizes these thematic findings of shared characteristics within each group and compares how related characteristics differ. Each characteristic was a coded theme attributed to each of the teachers within that category. For example, each of the High SMK/Low STE group teachers claims that developing confidence in their science teaching requires gaining more experience and practice rather than needing more SMK. However, each of the teachers from all other groups expressed the way to develop more confidence by first gaining more background knowledge in the subject area.

<table>
<thead>
<tr>
<th>Codes</th>
<th>Definition</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Science difficult because of knowledge content’s nature</td>
<td>Teacher demonstrating that students struggle in science because the content itself is inherently difficult due to the content’s complex, abstract, or complicated nature.</td>
<td>“Abstractness,” or “complexity” of a subject is the primary reason students find some physical science challenging. Other topics are “tangible or more easily observed.” (Camila, Jessica)</td>
</tr>
<tr>
<td>Science difficult because of teacher’s instruction</td>
<td>The teacher places the locus the responsibility on themself for whether a student succeeds or struggles in science.</td>
<td>Karalee said she couldn’t determine most effective teaching topic, but rather “students’ performance determines that.”</td>
</tr>
</tbody>
</table>
### Table 9

**Shared Characteristics Within Each Interviewed Group**

<table>
<thead>
<tr>
<th>Low SMK / Low STE</th>
<th>Low SMK / High STE</th>
<th>High SMK / Low STE</th>
<th>High SMK / High STE</th>
</tr>
</thead>
<tbody>
<tr>
<td>• More teacher-centered lessons in physical science and student-centered lessons in life science</td>
<td>• Teacher claims science is difficult because of knowledge content’s nature.</td>
<td>• Relied on skills or resources outside of science understanding to teach science</td>
<td>• More student-centered lessons in both physical and life sciences</td>
</tr>
<tr>
<td>• Teacher claims science is difficult because of student</td>
<td>• Confident teaching life science, which they also know most about</td>
<td>• Claim a physical science topic as their least effective teaching</td>
<td>• Teachers held themselves accountable for science being difficult for students to learn</td>
</tr>
<tr>
<td>• Claim more SMK is needed to develop confidence in teaching</td>
<td>• Claim a physical science topic as their least effective teaching, and know the least</td>
<td>• Claim more teaching experience and practice needed to develop confidence in teaching</td>
<td>• Claim a physical science topic as their most effective teaching</td>
</tr>
<tr>
<td></td>
<td>• Claim more SMK is needed to develop confidence in teaching</td>
<td></td>
<td>• Claim more SMK is needed to develop confidence in teaching</td>
</tr>
</tbody>
</table>

Eight of the 11 teachers described a physical science lesson as one they felt they were least effective in teaching. All of them, except one, included teachers with higher knowledge in both disciplines but low teaching efficacy and those who may have had lower background knowledge but scored significantly higher in their efficacy towards teaching. They felt they were less effective at teaching the physical science topic due to a self-proclaimed lack of background knowledge. A few also mentioned less teaching experience with the topic and difficulty for students to understand the material as reasons why they were less effective.

Both groups of teachers with low SMK claim that students who lack the necessary background knowledge cause students to struggle in science. This belief directly contrasts with the High SMK/ High STE group of teachers who hold themselves accountable for
the student’s academic performance in science. All but one of the teachers with high STE explicitly expressed a sense of teacher responsibility for student success. For example, when Jessica, a teacher with high STE, was asked why energy is difficult for students, she immediately responded, “because I’m not the best teacher at it.” Compare this with the statement from Ally, a low STE teacher who says that students struggle with “wave patterns” because “it’s a little complicated with all the vocabulary of that one.” Higher STE teachers tend to recognize their role in affecting student learning outcomes more so than low STE teachers.

Commonalities Across Groups

Across both high SMK groups, there was a greater tendency for these teachers than lower SMK teachers to provide more student-centered lessons and engage their students in more non-scripted activities. Every participant in the high SMK category described their lessons using phrases that indicated the focus of the activity was on the students and less on the teacher, as well as enacted class activities that were more teacher-constructed plans instead of relying on district-provided or outside sources. On the other end of the knowledge spectrum, every teacher across the low SMK groups indicated teacher-centered instructional descriptions and scripted activities. Only two high SMK teachers described scripted activities, and only two high SMK teachers reported teacher-centered instruction. These findings suggest that teachers more knowledgeable in science tend to think about how students engage in activities when considering a lesson. Furthermore, when reflecting or planning lessons, those with less science knowledge tend to consider more about what the teacher or whole class does than
what each student may be doing. These low SMK teachers also feel the need to rely on resources found online or provided to them. Lastly, the low SMK group of teachers unanimously claim the nature of science concepts as the reason science is challenging for students.

Regarding commonalities across the STE groups, there are mixed results. No STE group, low or high, showed a unanimous coding for any one code. However, teachers across the low STE category had double the number of teacher-centered descriptions compared to the high STE teachers, and only one teacher with no teacher-centered descriptions. On average, low STE teachers had at least twice reported a teacher-centered description based on code frequency, compared to only one instance for each of the few High STE teachers that used teacher-centered descriptions. These findings indicate that lower STE teachers are more likely to recall and report lessons that focus more on what the teacher is doing than what students are doing. All groups, except the high SMK/Low STE group, describe needing more background knowledge to develop confidence in teaching science.

In summary, low SMK teachers use more teacher-centered perspectives when describing lessons. Additionally, they rely on district or website-provided scripted lessons. Low SMK teachers are also much more likely to reason that the science content is challenging for students to learn because of the content’s nature. High SMK teachers, on the other hand, use a student-centered lens to describe their lessons and adapt or modify their curriculum to utilize nonscripted strategies.
High SMK/High STE Group Themes

Five themes emerged from the characteristics shared between participants within the High SMK/High STE group. First, the teacher participants described their typical approach to teaching their most effective topic as engaging students in more hands-on and student-centered activities. Second, each teacher regarded their most effective teaching as when they were teaching a physical science topic. The third theme to emerge is that teachers with high SMK and high STE each claimed they enjoy teaching physical science as some of their favorite topics to teach in science. Fourth, they reported themselves accountable for why some science is difficult for students to learn. Lastly, the teachers of this group all claimed that more SMK is needed to develop confidence in teaching. I will report on these five themes in further detail in the following sections.

Student-Centered Lessons

When asked to describe how the participants typically taught these lessons, the responses primarily focused on activities the students were engaged in (student-centered) instead of remarks about what the teacher was doing (teacher-centered). Student-centered activities included student experimentation, model development, data collection, data analysis, and asking questions. These are crucial science and engineering practices within the Next Generation Science Standards. As evidence of student-centered activities, Hannah, a fourth-grade teacher with 13 years of teaching experience, describes a lesson where Sphero robots are used for students to record stopping distance to measure changes in energy for different speeds of balls. She describes her students graphing and analyzing the data to detect emerging patterns. She also describes the students designing and
conducting their own investigation with the robots. Because her descriptions focus more on what the students were doing than what she or the entire class did, this is classified as a student-centered lesson summary. Other examples of student-centered characterizations of lessons are found in Table 10.

**Table 10**

*High SMK/High STE Quotes of Student-Centered Instruction*

<table>
<thead>
<tr>
<th>Teacher</th>
<th>Student-centered instruction quotes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Karalee</td>
<td>“The idea was that we were combining substances and there was some sort of reaction. … They explored a little bit and they collect some data on the exploration that we do…. We’ve got those three dimensions that we’re trying to incorporate. They had to then design an experiment that they would do to figure out which one of these ingredients, and there were, I think, five or six ingredients that I had that this boy [in the video] wanted to make elephant toothpaste. … It’s interesting because some of the kids just say, “Oh, put about a cup of this in there, and a cup of that.” And it’s like, “Wait a minute. Do we really need a cup? Do we need that much?” But since that’s the evaluate part of the Five E’s, that’s just part of the feedback I give after they’ve turned it in.”</td>
</tr>
<tr>
<td>Hannah</td>
<td>“We use those [Sphero] robots and we measured the speed of them. We measured the distance they traveled after it stopped. …I really spend a lot of time graphing the data and having them create their own data and then analyzing it and talking about what you know, and what do you notice…. I may have had them try to create their own investigation after with whatever they wanted. And that one, that’s really fun. Most of them they do just hitting something and seeing how far it rolls or whatever.”</td>
</tr>
<tr>
<td>Leah</td>
<td>“Each team had a tray of materials that I had prepared ahead of time. And then each team was assigned a property of matter. Is it reflective? Does it conduct electricity? Is it magnetic? And then each team conducted their experiments with the objects that they had and had to keep records, graph that on their table, which things were or were not had that property. And then we came back together for the last five minutes of class to discuss their different discoveries.”</td>
</tr>
</tbody>
</table>

**Claim Physical Science Topic as Their Most Effective Teaching**

All teachers in the High SMK/ High STE category regarded their most effective teaching when teaching a physical science topic (e.g., properties of matter, energy, earth surface interactions). Their most common reasons for what contributed to their
confidence in teaching physical science topics include their background knowledge and their training or formal education. For example, Hannah and Karalee received a STEM endorsement credential while an elementary teacher, claiming that their background knowledge has helped them teach energy and properties of matter more effectively.

When asked how she developed confidence in teaching energy and outer space topics, Hannah stated, “I think my STEM endorsement and the stuff I’ve done with the state.” Although there is no mention of a STEM endorsement, Leah described the elective coursework she completed in college as mostly geology courses as the main reason she is confident in teaching about earth’s surface interactions:

I do really well with the earth surfaces. I love geology and I’ve had a lot of geology classes. In college, not as part of my teaching. My first major, it was park and recreation management, and I had a lot of geology classes in that. Just electives. When I had to have science credits, that’s what I always chose.

Part of Leah’s confidence in teaching earth science “really well,” stems from her interest and frequently taking geology courses in college.

*Enjoy Teaching Physical Science Because of SMK and Hands-On*

Each of the High SMK/High STE teachers also claimed the topic they enjoy teaching most is a physical science topic. Two common reasons that the teachers reported for why they chose a physical science topic as enjoyable were (1) the ability for students to engage in hands-on activities that were fun and (2) these were topics the teachers described as knowing the most.
Two of the three teachers in this group explicitly described their accountability for student performance, which was not the case in other groups. For example, Karalee described her most effective lesson as producing the highest student performance. She claimed that she could not say that she is effective at one topic or another but that her “students’ performance determines that.” In other words, Karalee holds herself accountable for student outcomes. By Karalee making a connection between how effective she is with how well students do on a performance assessment indicates Karalee views her teaching performance as what leads to student outcomes. Similarly, when I asked Hannah what makes specific science topics difficult for students, Hannah replied that although students may have struggled recently with the night sky topic, she “may have pushed it too quickly for them thinking it was going to be simple” that year. In this statement, Hannah took responsibility for how her students were learning content by suggesting that an adjustment of her teaching pace would improve student performance rather than students or content needing to change. In contrast, teacher participants from the other groups claimed circumstance, vocabulary, concept abstractness, or student ability as the reason students struggled learning science, Hannah and Karalee did the opposite and vocalized their role in student learning.

Claim SMK is Needed to Develop Confidence in Teaching

Each participant in the High SMK/ High STE group claimed that confidence in teaching science comes from knowing more about the topics one teaches. Karalee, for
example, says she reads and learns the topic to develop her confidence. Hannah says she improved her science teaching confidence by learning the concepts and how to teach them through her STEM endorsement program. Last, Leah postulates that her confidence comes from “definitely me understanding it because I am very confident about teaching anything I have to teach as long as I know what I’m teaching.”

**High SMK / High STE Group Findings by Interview Question**

Table 11 shows which subject area topics the High SMK/High STE teachers used to respond to some interview questions. These and other results from their interview responses, such as how the teachers approached instruction in the classroom, are further detailed in Table 11.

**Table 11**

*High SMK/High STE Group Findings by Interview Question*

<table>
<thead>
<tr>
<th>Teacher</th>
<th>Topics they enjoy teaching</th>
<th>Topics they claim to most effectively teach</th>
<th>Topics they claim to least effectively teach</th>
<th>Topics they claim to know most</th>
<th>Topics they claim to know least</th>
<th>Topics they believe students struggle with</th>
</tr>
</thead>
<tbody>
<tr>
<td>Karalee</td>
<td>No topic in particular</td>
<td>Properties and changes of matter (PS)</td>
<td>Cycling of Matter/ Food Webs (PS/LS)</td>
<td>Matter (PS) Geology (PS)</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Favorite Teaching Topics

Karalee enjoys teaching about properties of matter and interactions because of the hands-on labs for the kids, as she remarks:

The kids can interact with it, and we can do that safely with some of the household types of items like vinegar and baking soda and things like that. And sometimes they’re already a little bit familiar with it because their moms have said, ‘Hey look at this’ or they may have made slime and goo.

Hannah characterizes herself as a “physical science person.” She says she really enjoys “the energy” standard because it is “physical science-heavy.” She also describes energy and waves topics as “really fun.”

When Leah responded to the prompt about her favorite topics she loves to teach, she started listing both fourth- and fifth-grade standards as she stated:

Heredity is always tons of fun, inherited traits and adaptations. You can’t beat magnetism and electricity, of course. And matter’s fun, properties of matter. Love the geology ones, the fossils, the earth surfaces. I just like science.

Most and Least Effective Teaching Topics

Karalee did not provide a specific topic in the interview that she felt she teaches most effectively. Instead, she expressed that she does not like to think one of her teaching topics is better than another. Instead, she often believes the end-of-level student scores inform her of where she is most and least effective. She then followed up with, “a lot of times the kids have some understandings that do not necessarily show up in those end-of-level tests.”

Although Karalee chose not to discuss any one topic that she was effective at teaching, she did declare her least effecting teaching topic as food webs and the cycling
of matter through ecosystems. Her reasoning for ineffectively teaching this topic is that she has not taught it very much as it is still new to her with the new state science teaching standards. Karalee relies on the district-provided lessons, she says, when teaching this topic.

Hannah stated that she is most effective at teaching energy standards because those are the ones she “feels pretty confident about.” On the other hand, Hannah believes she is least effective at teaching about fossils. She reasons that she is ineffective in teaching some of the life science and earth science topics because she does not know enough natural phenomena to use as examples in the lessons. She states:

> I don’t have enough examples. And that’s the other thing with earth science and life science. It’s a lot of work to try to find good data about... They always use the same data a lot of the time. Like with ecosystems changing, they always use the wolves in Yellowstone.... Another thing that makes it really hard with the life and earth sciences, is I am not an expert with those things, and so it’s really hard to find really good quality phenomena, especially with data that allows them to analyze that.

Leah described her most effective teaching topics involving earth surfaces, such as erosion, volcanoes, and earthquakes. These are also the topics she claims to know the most. Leah reasons that she effectively teaches earth science because she loves geology and took many geology classes in college as her go-to choice for elective and science classes. When discussing her least effective teaching topic of properties of matter, she similarly reasoned that she does not teach that topic well because she has little background knowledge in chemistry and never took chemistry classes in college.

**What They Say They Know Most/Least**

Although not explicitly responding to a question asked about what topic she
believes she knows most about, Karalee mentioned in her interview that she was very familiar with geology and matter because these were standards she had previously taught. However, because of time constraints for Karalee, it was never discussed which topic she believed she knew the least.

Hannah stated she knows most about the structures of plants and animals and energy. Regarding the animal and plant structures, she says she knows it well because she has shown students many phenomena with animals and had her “biology friends” teach her parts of a flower so they could dissect them in class. However, she expressed that she knows little about the “waves,” “space,” and “fossils” topics without giving reasons why.

Leah believes she knows most about earth science because of her background and college experience in geology classes. However, she is less knowledgeable about other physical and life science topics. She believes she knows little about physical science because she has never had a college or professional development class in the physical sciences. She says she would take a physical science professional development class if given the opportunity.

**Physical and Life Science Lesson Descriptions**

Karalee describes her science lessons as typically involving the Five-E structure (Engage, Explore, Explain, Elaborate, Evaluate). While describing a lesson about properties and changes of matter, she mentioned she often likes to start with a video as a phenomenon to engage the students. She uses a video because in videos “chemical reactions can be more dramatically shown when you show fireworks or if you show a giant elephant’s toothpaste just spurting up in the air.” She described how they explored
elephant toothpaste in one lesson and collected data with a similar experiment. Students had to design an experiment to determine which ingredient a boy in the video needed to make elephant toothpaste. Her characterization of the lesson was student-centered in that she used many descriptions that focused on what the students were doing, saying, and thinking more so than what she, the teacher, was doing with the whole class.

Hannah, when teaching students about the function and structures of different organisms, says she likes to show a video or picture that leads to a discussion. For both the function and structure of animals or plants, she states that she mainly talks about them in a discussion format rather than any “investigative” format.

Hannah described a lesson on energy where she used Sphero robotic balls to observe, measure, record, and analyze stopping distance. She stated that students use this data to make sense of each ball’s energy based on student-developed graphs and patterns they noticed. Compared to her description of structures and functions of living organisms, this description was more student-centered, with a hands-on emphasis on the activities.

Leah describes a lesson on properties and changes of matter as one where she used the district-provided resources and reviewed those first. The district provides her with presentation slides, online resources, and student journals. She mentioned she does not always like to use all they provide but rather insert or adapt it to her stuff. She says that her total time to teach science is only 30 minutes twice a week. She likes to start with a phenomenon she shows students within the first 5 minutes and gives the students to have group discussions, followed up with a 10-minute lecture on the new content. She prepared a tray of materials for her students for her most recent lesson. Each team was
assigned a property of matter to determine which of their materials had those properties (e.g., reflective, conductive, magnetic). Each table recorded their results with a graph of the results. They then held a whole-class discussion on the results.

Leah described a recent life science lesson where she had students use a growing table in their classroom to grow plants that students used to tweak different growing conditions – “some didn’t get watered, some didn’t get light.” This year she also plans to have her students bury a pumpkin in soil with “litter” and observe the outcome over time. Additionally, she intends to expand her plant-growing capabilities by acquiring a classroom greenhouse in the near future. Like Leah’s physical science lesson description, her characterization of life science lessons was also very hands-on and student-centered.

**How They Develop Confidence in Teaching**

Karalee says she relies on the district for resources and training to develop confidence in topics she feels less effective at teaching. She remarked that the district does provide more scripted lessons they “can fall back on.”

When I asked Hannah how she developed confidence in teaching, she first responded with her successes with end-of-level student assessments. Then, when asked to describe why she thinks she’s done so well with her students performing well in science, Hannah said she attributes her success to her STEM endorsement. She also associates her success with experience with assisting the state with developing and evaluating state-wide assessments and participating in professional development that familiarized her with the newer state teaching standards. Hannah eventually added that she develops confidence by “trying things out and using different resources.”
Leah remarked, “I can’t teach stuff I don’t know.” Her way of developing confidence in teaching topics is to research, read, and learn more about the topic. She uses textbooks, classroom materials, and online materials to develop an understanding of topics. She sums up her belief about knowledge influencing her teaching confidence by stating:

I am very confident about teaching anything I have to teach as long as I know what I’m teaching. So it’s about me having the knowledge base in order to teach it effectively because then I can figure out what’s going to be most beneficial for the students or maybe what way to approach it, the they will understand it best.

**Topics Difficult for Students**

Out of time constraints, the interviewer could not ask Karalee about which topics she believed students struggled with the most.

Hannah does not believe one topic is “necessarily difficult for students” but instead believes there are misconceptions that students carry with them. For example, she cites deeper layers of soil where older fossils are found and stars in the night sky being three-dimensional difficult for students because of their misconceptions. She also says understanding how light rays bounce off objects and into the eye is difficult for students due to preconceived conceptions.

According to Leah, the most difficult topics for her students to learn are the ones that involve abstract concepts, such as properties and changes of matter. She says her school’s geographic location makes for more accessible learning on other topics, such as earthquakes, volcanoes, and erosion, because “there is evidence all around them… they understand all that.” However, matter at the molecular level says Leah is “hard to touch,
to feel, to see transferring of gases,” making learning about matter difficult for fifth-grade students.

Low SMK/High STE Group Themes

Jessica and Camila are the two low SMK/High STE teachers. Jessica has taught fourth grade for 5 years, and Camila has taught fourth grade for 7 years.

Two themes emerged when reviewing all the data and codes for this group of participants. First, the teacher participants depict that students struggle with physical science topics due to (1) the “non-tangible” nature of the content, and (2) the complexity of the content itself. The second emergent theme is that teachers believe that knowing more content knowledge will help them effectively teach better with more confidence.

This section examines the two themes and provides evidence of these findings.

Students Struggle with Topics that are Not Tangible

One theme that emerged from analyzing the statements about topics that students struggle with is that both Jessica and Camila remarked that the concepts most difficult for students are physical science topics because they are abstract or not tangible. For example, Camila says that learning about objects in the sky is difficult because:

Even though you can see the sky and the patterns, it’s not tangible. It’s not like waves that we do sound experiments with sound waves, or energy when we use flashlights or morse when we transmit the message. This is talking about the sky. Something they won’t really touch. It’s not tangible.

Camila’s reason for why students struggle with learning about objects in the sky is because they can’t experience them with a hands-on or tangible approach like they do
with other topics such as waves.

Likewise, Jessica argues that energy is both complex and not tangible. Thus, energy is “murky or confusing” to the students. She asserts, “I think energy’s complex for fourth graders. It’s just not tangible. Besides light energy, you can’t see it…. I just feel like it’s more abstract for some reason. Just something you can’t really touch.”

Like Camila, Jessica believes that the non-tangible concepts are too difficult for students because they can’t see or touch them. Both cite abstract physical science examples believing that these untouchable or unobservable concepts create the greatest challenge for students in learning the concepts.

**Content the Reason for Science Being Difficult for Students to Learn**

Rather than talk about their teaching effectiveness or holding themselves accountable for why students struggle to learn a topic, Camila and Jessica shift the accountability to the science content being the reason why students struggle to learn some science topics. Both argue that the “abstractness,” or “complexity” of a subject is the primary reason students find some physical science challenging. Both teachers remarked about other topics being more “tangible” or more easily observed. However, those topics that could not be easily observed, or touched through “hands-on” experiments, were most difficult for the students.

**Confident Teaching What They Know Most**

Another emerging theme is that this group of teachers believes they can teach effectively what they know the most about and least effectively what they know the least
about. For example, both teachers in this category brought up physical science topics as their least knowledgeable and least effective teaching content areas. Additionally, the topics they each claim to know the least about are also the same topics they believe they teach less effectively. For Camila, this was waves, and for Jessica, it was energy.

On the other hand, Camila and Jessica expressed how they are most knowledgeable about the living organism’s structures and functions and can teach it to their students most effectively.

Little is mentioned explicitly about the nature of this knowledge being subject matter or PCK. Camila mentions the need to understand the science engineering practices in the standards to help her teach the content better, and Jessica argues the need for “digging deep into the subjects” to help develop her confidence in teaching science.

**Low SMK / High STE Group Findings by Interview Question**

Table 12 summarizes the findings from teachers’ responses to interview questions regarding which topics they claim to enjoy, know most or least, effectively teach, or believe students struggle with.

**Favorite Teaching Topics**

Camila’s favorite science topic to teach is waves because she feels she “can explore the most” with sound waves and light waves when it comes to what she does with her students. Jessica enjoys teaching about patterns in the sky and living organisms. She claims these are her favorite science topics to teach because she understands the topic and feels like her students can more easily understand the sky and living organisms. For
Table 12

Low SMK/High STE Group Findings by Interview Question

<table>
<thead>
<tr>
<th>Teacher</th>
<th>Topics they enjoy teaching</th>
<th>Topics they claim to most effectively teach</th>
<th>Topics they claim to least effectively teach</th>
<th>Topics they claim to know most</th>
<th>Topics they claim to know least</th>
<th>Topics they believe students struggle with</th>
</tr>
</thead>
<tbody>
<tr>
<td>Camila (4th grade)</td>
<td>Sound and Light Waves (PS)</td>
<td>Living Organisms (LS)</td>
<td>Sound and Light Waves (PS)</td>
<td>Living Organisms (LS)</td>
<td>Waves (PS)</td>
<td>Patterns in Sky (PS)</td>
</tr>
<tr>
<td></td>
<td>Living Organisms (LS)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

example, Jessica describes the patterns in the sky topic as:

Something I understand and the students just get that one easier, I think. And they get really excited about it. It’s like their first experience, really looking into the sky at stars. We use a star chart app and it’s their first experience with that. That’s fun to see how excited they get and when they realize how smaller sun is really compared to everything, they’re just so shocked. It’s fun to see.

Although the interviewer did not explicitly ask Camila about her least favorite topics, she described energy as a least favorite topic because she feels that is a topic she least understands.

Most and Least Effective Teaching Topics

Camila believes she is most effective at teaching about the structures and functions of animals or plants because that is a topic on which the students would have the most background knowledge and vocabulary. On the other hand, Camila notes that she is least effective at teaching students how waves work because she believes there are
too many unfamiliar words and concepts around this topic.

Jessica describes herself as most effective at teaching patterns in the sky (Earth’s rotation and motion around the sun) and the topic of living organisms. Jessica says she effectively teaches the topic of moon, stars, and sun because “it’s not as abstract to me as energy, but I’m interested in the sky and the stars. So, I think I already had like a good background knowledge of it, so made it easier to teach.” Her least effective teaching is on energy and collisions because she has less background knowledge of energy, and it is still new to her.

*Physical and Life Science Lesson Descriptions*

When the interviewer asked Jessica to describe a lesson on living organisms as a topic she felt she was highly effective at teaching, she opted to discuss a more recent lesson on energy she had just taught. Earlier in the interview, Jessica claimed she is least effective at teaching energy.

In describing her recent lesson on energy, Jessica discussed how she showed her students a video of a phenomenon from Generation Genius (an online elementary science lesson website) to garner student interest. She then held a whole class discussion about the content of the video for about ten minutes before starting the project. Jessica used Vex robotic kits for the students to design and construct “a system with a pulley that would move a box from the ground to a tree house.” The project’s goal was to move a box up to a higher position as a pretend scenario of getting a box from the ground to the entrance of a treehouse. After the project, students spent time writing in science journals, answering “their conclusion questions that brought it all back together.” When the
interviewer followed up with Jessica about what concepts she wanted the students to learn because of the activity, she mentioned she wanted the students to understand that energy can convert from one type of energy to another. These energy conversions included electrical energy to mechanical energy when the robots move the box upwards. She mentioned at the end of her lesson description that she felt the students learned much due to the lesson and activity. Jessica’s description of her lesson on energy portrays more of what the students were doing rather than what she, or the class in general, was doing. This is an example of a more student-centered lesson representation.

The interviewer later followed up with Jessica with a request to describe a lesson on living organisms, as this is what she considers the most effective topic she teaches. She related an account of a recent lesson where she discussed the function of bird beaks and why they can be unique for different birds. To help the students make sense of the function of the beaks, she handed out tools to simulate beaks, such as tweezers, popsicle sticks, and chopsticks. Students had to try and grab bolts or washers with these fake beaks. She mentions they had whole-class discussions about why different birds have environmental advantages with different styles of beaks due to adaptation.

Camila described her life science lesson as showing students a video of an animal hunting another animal. She starts this way by engaging students in a phenomenon and inviting them to observe it and record it in a science journal. Next, she introduces the topic and asks students to describe their observations and what structures the animal has to succeed in the hunt. Students also write questions they have about it. When Camila described her physical science lesson on waves, she mentioned that she uses a manual
that lays out the step-by-step instructions for each activity and questions for the lesson. She says she follows a similar structure to her shared life science lesson – starting with a phenomenon, making observations, and discussing the topic. However, in her interview descriptions, she was much more descriptive about the activities she and her students engaged in during the life science lesson than in her physical science lesson.

**How They Develop Confidence in Teaching**

Both Camila and Jessica remarked that background knowledge is vital to effectively teaching a subject. For example, Jessica mentioned she developed more confidence in teaching science by “learning more, really digging deep into subjects, watching videos on YouTube really helped me, and seeing if there’s other reading material that’s related, just learning.” Jessica also planned to read through a list of books this summer to build her understanding of the science standards. However, Jessica did not mention whether the books she plans to read or resources she uses to learn were strictly about pedagogy or content knowledge.

Camila says she researches topics she does not know to help her teach more effectively. She also mentioned that knowing how to use the science and engineering practices found in the state teaching standards helps her have confidence in her teaching.

**Topics Difficult for Students**

Jessica says that energy is the most challenging topic for students to learn because of its complexity, “many different forms,” and the abstract nature of the topic. For example, she argues that energy cannot be touched or seen except for “light energy.” This
abstractness makes it harder for students, she says. Energy is also tricky for Jessica to understand, as she noted early in the interview, and she struggles to teach it effectively from her perspective. She also postulates that the student’s difficulty with energy is “maybe because I feel like it’s murky or confusing.”

Similarly, Camila says that teaching students about objects in the sky is teaching something to the students that “they won’t really touch. It’s not tangible.” This abstract nature is her reason for why students struggle with the topic of patterns in the sky.

**High SMK/Low STE Group Themes**

Karina and Rosalina are the two teacher participants in the High SMK/Low STE group. Both are fifth-grade teachers. Karina has taught elementary for 23 years, with at least three of those as a fifth-grade teacher. Rosalina has been teaching fifth grade for the past 5 years.

Two themes emerged from the High SMK/ Low STE group codes. The first theme is that these teachers tend to rely on their outside skills or online resources to assist in their teaching. The second theme is that these teachers believe more practice and experience is what helps improve their confidence in teaching.

**Teachers Relied on Outside Skills or Resources to Teach Science**

A common pattern between both teachers is that they mentioned skills they relied on from nonteaching career experiences or resources from outside sources they used. For example, Rosalina expressed her expertise in calculations and data analysis as something she teaches the kids and relies on a lot. She underscores the need for students to develop
these skills and says her background in accounting and working with data provided her with the needed skills to help students in science.

Karina summarized her lesson planning and teaching as relying heavily on prepackaged and sequenced lessons through a district-subscribed program called Amplify. She also says she downloaded and used online scripted PowerPoints to teach and relied on online videos to provide better explanations. As evidence, Karina states:

Looking at Amplified, also, we tapped into Generation Genius, which the kids absolutely love. And then we pulled some stuff off of just Teachers Pay Teachers that had to do more with some PowerPoints and some reading. That was just a little bit more inviting. And really we searched a lot on the internet for videos that could explain in a little bit more knowledgeable ways than I was able to.

This statement is another example of a scripted lesson because of the way Karina describes her reliance on PowerPoints from a website, her use of online programs for student activities, and use of YouTube videos to explain concepts. She never mentions how she may have modified or adapted the resources or how she explained the concepts.

Claim More Teaching Experience and Practice Needed to Develop Confidence in Teaching

Rosalina and Karina assert that the best way to develop confidence in teaching science is to do it or practice teaching. Teaching, according to Karina, develops a sense of curiosity. That curiosity makes a teacher want to know more about the content knowledge or how to teach that content. For Rosalina, refining your teaching each year through reflection develops confidence. For example, Rosalina states:

So, as I create lessons and then I see what works and doesn’t work and then I make adjustments. Say, ‘Okay, this is what I can do better.’ Then try to adjust it based off of the current year group of kids and what their strengths and weaknesses are.
Unlike most other interviewed teachers, Rosalina does not talk about the need for more background knowledge to build her confidence. Instead, she says she learns by trying it out, seeing what works or doesn’t work, and then adapting. For Rosalina, experience and reflection breeds teaching confidence.

**High SMK/Low STE Group Findings by Interview Question**

Table 13 summarizes the findings from teachers’ responses to interview questions regarding which topics they claim to enjoy, know most or least, effectively teach, and believe students struggle with.

**Table 13**

*High SMK/Low STE Group Findings by Interview Question*

<table>
<thead>
<tr>
<th>Teacher</th>
<th>Topics they enjoy teaching</th>
<th>Topics they claim to most effectively teach</th>
<th>Topics they claim to least effectively teach</th>
<th>Topics they claim to know most</th>
<th>Topics they claim to know least</th>
<th>Topics they believe students struggle with</th>
</tr>
</thead>
<tbody>
<tr>
<td>Karina (5th grade)</td>
<td>Properties and changes in matter (PS)</td>
<td>N/A</td>
<td>Earth’s Systems (PS)</td>
<td>“All of them”</td>
<td>Earth’s Systems (PS)</td>
<td></td>
</tr>
</tbody>
</table>

**Favorite Teaching Topics**

Karina and Rosalina mentioned they enjoy teaching about properties and changes in matter the most. Karina says she enjoys this topic the most because of the “excitement that the kids have when they start realizing that things aren’t made out of just nothing and
that they start being able to understand how things can be combined, that they can do a little bit of experimenting with it.” She also adds that she enjoys the hands-on experiments that accompany the topic. Rosalina enjoys teaching about matter’s different properties and magnets because “those are really fun for the kids to learn, to explore.” Both responses to their favorite science teaching topics exemplify teacher enjoyment based on the students’ experience. Moreover, both teachers cite the use of hands-on student experiments as part of their reason for enjoying such topics.

**Most and Least Effective Teaching Topics**

Rosalina believes she is most effective at teaching her students about earth’s interacting systems, particularly the geosphere’s interaction with the hydrosphere and atmosphere. She says she is most effective in teaching about interacting Earth systems because “it’s not so much me, it’s just easier to pull information in, examples, other things that was easy for the kids to be able to see and relate to.”

Rosalina asserts that she is least effective at teaching students how to analyze and interpret data, particularly regarding earthquakes and volcanoes. She says she based this belief on her students’ end-of-level performance test results. However, she also said that she does not believe the underperforming student results of the state’s end-of-level assessment reflect her teaching performance.

Because of Karina’s time constraints during the interviews, she was not explicitly asked about what she believes she most effectively teaches. Nonetheless, Karina described her least effective teaching topics as earth’s systems, weathering, and erosions. She states, “I think partly I had a tougher time explaining that one because we didn’t
really do a lot of experiments with it, which I think the experiment is really what connects the kids to the understanding.”

What They Say They Know Most/Least

When asked about what science topics the teachers believed they knew most about, Rosalina declared knowing most about many science and engineering practices, especially analyzing and interpreting data and using mathematics and computational thinking. In addition, Rosalina believes her background as an accountant for 20 years gives her a unique background knowledge for skills that students use in science.

Karina said she knows most about how matter and energy cycle through ecosystems, such as from an environment to an animal. She explains she knows more on this topic because, she says, “it kind of makes sense, because hello, I am a consumer. I mean there is just more relatability.”

Physical and Life Science Lesson Descriptions

Rosalina used pictures of an Indonesian volcano eruption to teach about interacting earth systems. She asked her students to draw pictorial models of how two “spheres” (geosphere, biosphere, atmosphere, and hydrosphere) interacted. She followed up with students in a whole-class discussion to ask how the spheres interacted. Following this segment, she did a similar activity with a “static picture of a flower in the desert soil.” Again, she had her students develop models and list how at least two spheres interacted.

In describing a life science lesson, Rosalina describes a lesson about the cycle of
energy and matter through an ecosystem:

For food chains, energy going through them, is trying to start with things with the decomposers, introduce the concept of how it can take matter, like leaf matter, grass matter, and these insects and other decomposers break it down and leave soil…. That was easy and at the same time it’s hard because I struggle with kids just doing book work for science. I hate book work for science, it’s so boring. And so when you’re just limited in resources, then it’s difficult to pull away from the bookwork for a lot of the concepts and the worksheets and whatnot. So that one I would have tried to make a game, game cards where they had to match, make a food chain type thing, build up with that.

This description is teacher-centered in that it focuses more on what the teacher is doing or preparing instead of describing the actions and activities the students are engaged in.

Karina described a physical science lesson on properties and changes of matter. She relied heavily on prebuilt scripted lessons, PowerPoints, and readings from various online resources and programs that her district subscribed to. She mentions briefly, “one of the experiments was to decide which substance was powdered sugar, and just the characteristics of each of them, if they were soluble.” Karina described her physical science lesson with a more teacher-centered approach. For example, there was very little mention of what the students actually did. Instead, Karina mainly summarized the resources she used, how she prepared, and only a few whole class events. Due to Karina’s time constraints during the interview, she did not expound on a life science lesson.

**How They Develop Confidence in Teaching**

Rosalina cites practice and teaching experience as the primary means of developing science teaching confidence. Similarly, responding to what helps her develop confidence in science topics she is less effective at teaching, Karina states:
Doing it. I mean, this sounds silly that you try to teach something that you’re not incredibly familiar with, but by teaching it, it creates my questioning, which means I have to answer it, which means I have to search a little bit more.

Rosalina suggests that the practice of teaching science naturally leads her to ask questions and therefore seek answers about the content she’s teaching. Rosalina implies that knowledge is key to confidence, but that this knowledge comes best by teaching.

For Karina and Rosalina, the experience of teaching more often develops a teacher’s confidence toward topics they have felt less effective at teaching. Karina reasons that by teaching it, a teacher will have questions about the knowledge needed to teach and is, therefore, more likely to search for answers to those questions.

**Topics Difficult for Students**

Rosalina argues that the cycling of energy in an ecosystem is the most challenging topic for students. She reasons that she believes the topic in the standards is still new to her and that the students cannot afford the needed experience with it. Given that Rosalina finds this topic difficult for her students, she describes how she developed a card matching game to engage students and help them understand the concept of food chains. When discussing the topic of energy in an ecosystem, she also cites that she does not like having students do book work because “it’s boring” and she avoids just worksheets for this topic. However, Rosalina understands the challenge for the students to understand how energy moves through plants and animals. Because of this, she has gamified some of the curricula and found means to keep them engaged.

Although not explicitly asked, Karina says that the topic that students give more of the “deer in the headlights’ look is when she teaches them the differences between
weathering and erosion in the geosphere. She says this is likely due to her ineffective teaching on the topic. Karina had just changed to teaching fifth grade 2 years ago, though she had taught fifth grade many years prior. Karina mentioned that she was still adjusting to learning the fifth-grade standards as the reason she thinks both she and her students struggled with the topic.

**Low SMK/Low STE Group Themes**

Three themes emerged using thematic analysis of the codes from the Low SMK/Low STE group. The first theme is that teachers enjoy teaching physical science topics over other topics in their standards. Second, the teachers rely on more step-by-step and scripted curricula provided by the district or online sources. Lastly, teachers in this group were more likely to describe a teacher-centered lesson when describing how they teach science.

**They Enjoy Teaching Physical Science**

All four interviewed participants who scored in the lowest quartile for SMK and STE share the similarity that they enjoy teaching physical science topics. These include electricity, energy, and observable patterns in the night sky. However, these same teachers also reported their least effective teaching topics as physical science. For example, Kimmy describes energy as a topic that is enjoyable because of the fun experiments and ease of the step-by-step:

Right now, I’m really enjoying teaching the energy part. I don’t know a lot about it, but I found a good resource that is making it a little more easy. Mystery Science just came out with step by step, and he’s got the patterns and I print the patterns and we’re able to make fun experiments.
The other two teachers from this Low SMK/Low STE group echoed the sentiment that they enjoyed teaching lessons if they had step-by-step instructions and the hands-on activities with the students were “fun” or “engaging.” For example, Erin remarks:

I want to say our funnest one is probably electricity. So our district actually got a program for us this year, which was really nice. So we made flashlights. In the past, I’ve had to come up with my own stuff and it’s really hard. So this year’s been really nice that we actually had a program and they sent us all the supplies with the program, which was really nice because I wasn’t trying to find stuff.

Ashton also describes one of her favorite topics to teach, saying:

I really like talking about the observable patterns in the sky. It’s something that kids seem to be really interested in and they’re excited about. It just has pretty easy experiments that you can do.

Ally expressed her enjoyment of teaching about energy because of the district’s supplied resources and activities the students could engage in:

I have to admit this district has provided this new program…. A couple things they did that were really fun that we loved was we did popcorn popping with the energy source. And then they also did melting ice cubes, and then they just did circuits.

In all four of the Low SMK/ Low STE teachers’ descriptions about topics they enjoy teaching, they describe curriculum that was provided to them. For Kimmy, she found the Mystery Science online program as a great resource for teaching energy with step-by-step guides. For both Erin and Ally, they used district-provided programs that included district-supplied equipment to go along with the hands-on activities. Kimmy, Erin, and Ashton each commented about how much easier the activities were because of having the needed supplies for each activity. The accessibility to both curriculum and supplies for activities contributed to their enjoyment of doing physical science.
Reliance on Scripted or Assisted Lesson Plans

Each of the elementary teachers in the low SMK/low STE group notably describes using district or online scripted lesson plans to assist their teaching, making it more approachable. This reliance on scripted lesson plans and curriculum resources from the district, or those found online, becomes more apparent in their teaching when all four teachers within the Low SMK/ Low STE group described the physical science lessons they taught. Nevertheless, descriptions of how the teachers enacted lessons in life science did not mention scripted lesson plans or district-provided presentations. Table 14 includes examples of these differences. The reliance on external resources and scripted plans indicates lower teaching efficacy. This teaching pattern heavily relies on physical science resources, plans, and guided presentations, aligning with the survey statistic that elementary teachers tend to have higher LSPSTE than PS PSTE.

Teacher-Centered Lesson Descriptions

An additional emerging theme is in the descriptions of physical science lessons in Table 14, which demonstrate a more teacher-centered description of how the Low SMK/ Low STE teachers would enact their physical science lesson. Rather than detailing what the students were mostly engaged in (student-centered), the teachers describe what they, or the class as a whole, is mostly doing (teacher-centered). For example, when Kimmy describes her lesson on energy through the use of roller coasters, she speaks a great deal about the preparation and the need to get “the patterns” and “print the patterns” to be “able to make fun experiments.” She then discusses how a class “talked about how the energy transfers and height gives it the stored energy.” When Kimmy describes her life
Table 14

*Low SMK/Low STE Group Quotes on Teaching Physical vs Life Science*

<table>
<thead>
<tr>
<th>Teacher</th>
<th>Science discipline</th>
<th>Quote on teaching approach for science lesson</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kimmy</td>
<td>Physical Science</td>
<td>“Mystery Science just came out with step by step, and he’s got the patterns and I print the patterns and we’re able to make fun experiments. We made a roller coaster type of thing where they talked about how the energy transfers and height gives it the stored energy.”</td>
</tr>
<tr>
<td></td>
<td>Life Science</td>
<td>“We had the aquarium come with their animals and kind of help teach some of those things. What we then did, is we kind of broke up into groups. I had some groups talking about reptiles and do research on reptiles. One on the amphibians and went on. So we broke up the groups and had small groups, kind of do some independent research on them and then, kind of present things they found to the class. We always talked about, well, now, what is it about the animal that makes it live in the desert? What is it about the animal that makes it live in the forest? How does it survive there?”</td>
</tr>
<tr>
<td>Erin</td>
<td>Physical Science</td>
<td>“So our district actually got a program for us this year, which was really nice. So we made flashlights. [The students] had a battery and aluminum foil, and they had to figure out how to get it to turn on and off with an LED light. … … So it’s just Mystery Science, so it’s just web based and then they have the lessons, and experiment, and then they actually send us all of the supplies that you need for each unit that you’re going to teach.”</td>
</tr>
<tr>
<td></td>
<td>Life Science</td>
<td>“We had to figure out how bones could move because bones can’t move without, so we made paper fingers and they had to figure out how to get the finger to bend with a string. And then we also did, how do blind people... let me think, what do people see who are blind? So we had to figure out how did the light filter through the retina, which was really fun. And then I bought upside down goggles that they put them on and everything was reversed. And they had to try to figure out and interpret the data and how quick your body adjusts to the information it’s getting.”</td>
</tr>
<tr>
<td>Ashton</td>
<td>Physical Science</td>
<td>“School district does have a lot of videos, so we’ve pulled from those. But, yeah. One of the experiments is to put some sort of floating, like a rubber duck or something in a bucket of water and bounce it to show the waves. So, yeah. Preparing for that would be getting your bucket of water and a little floating device… The district does have Nearpods that they’ve created, and so I do use those quite often, too.”</td>
</tr>
<tr>
<td></td>
<td>Life Science</td>
<td>“There was one lesson where they were supposed to compare modern-day organisms with the fossils that are similar to them. I actually have a trilobite fossil, so I tried to find a picture of the modern day. I can’t remember now what that one’s called, but it lives in the ocean, the modern day one. And we compared and contrasted how those are similar and different. And I found other pictures, too, of fossils with their modern animals and compared and contrasted their structures and functions.”</td>
</tr>
<tr>
<td>Ally</td>
<td>Physical Science</td>
<td>“I feel like the energy was really good. It had a lot of hands on that we lot. And they were in the lesson plans that they gave us, they were in the Nearpods.”</td>
</tr>
<tr>
<td></td>
<td>Life Science</td>
<td>“[The students] do stuff with pine cones and this and that. So what are some differences between plants and animals? How are their impact and what are the structures of that? It was a little bit better and we try to do a lot of group work and things like that. So they can work together and pull apart things.”</td>
</tr>
</tbody>
</table>
science lesson, she explains how the students “broke up” into “small groups” to talk “about reptiles and do research on reptiles.” She mentions that the students would “do some independent research” and “present things they found to the class.” All life science lessons described by the Low SMK/Low STE teachers involve more descriptions of what the students were doing than what the teacher was doing. However, this was not the case for the physical science lesson plans discussed during the interviews within this group.

**Low SMK / Low STE Group Findings by Interview Question**

Table 15 summarizes the findings from Low SMK/Low STE teachers’ responses to interview questions regarding which topics they claim to enjoy, know most or least, effectively teach, and believe students struggle with.

**Table 15**

*Low SMK/Low STE Group Findings by Interview Question*

<table>
<thead>
<tr>
<th>Teacher</th>
<th>Topics they enjoy teaching</th>
<th>Topics they claim to most effectively teach</th>
<th>Topics they claim to least effectively teach</th>
<th>Topics they claim to know most</th>
<th>Topics they claim to know least</th>
<th>Topics they believe students struggle with</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kimmy (4th and 5th grade)</td>
<td>Energy (PS)</td>
<td>Sound and Waves (PS)</td>
<td>Earth Systems (PS)</td>
<td>N/A</td>
<td>N/A</td>
<td>Energy (PS)</td>
</tr>
<tr>
<td>Ashton (4th grade)</td>
<td>Patterns in Night Sky (PS)</td>
<td>Fossils (LS)</td>
<td>Energy (PS)</td>
<td>N/A</td>
<td>N/A</td>
<td>Structure and Functions of Organisms (LS)</td>
</tr>
</tbody>
</table>
**Favorite Teaching Topics**

Erin mentioned her favorite topics to teach in science are “anything I can do hands-on with, that’s not too much lecturing, but the kids get to do experiments with.” Kimmy says her favorite topic to teach is energy, not because she knows much about it, she remarks, but because of the resources she must use to teach it.

For similar reasons as Erin and Kimmy, both Ashton and Ally comment that their favorite topics as physical science topics are enjoyable because they have more “hands-on experiments that engage students.” Ashton says she enjoys teaching about the night sky because the topic involves “easy experiments.” Ally says she loves to teach about energy and sound because the district-provided resources allow her to engage students more quickly. She adds that she has more “background knowledge” on energy and sound and “feels confident in teaching it.”

**Most and Least Effective Teaching Topics**

Erin stated that she believes she most effectively teaches about organisms functioning in their environment because the unit deals with the human body, and students can relate well to learning about their bodies. According to her, she is least effective in teaching sound and waves because she has no background knowledge on this topic.

Kimmy says she is most effective in teaching about waves because she knows most about them and feels she has enough background experience teaching them well. Her proclaimed least-effective teaching topic is earth science because she lacks background knowledge, stating that she never had many content science classes in
college. She mentions she relies on her son, who has a Ph.D. in geophysics, to help her understand the lesson content involving earth science.

Ashton describes her most effective teaching as when she teaches about fossils. She uses lesson plans she has modified and crafted over the years. However, when describing her least effective teaching topics of energy and waves, she mentions that she tends to rely on district-provided lesson plans and experiment resources while also using the scripted presentations provided by her district.

Ally is most effective at teaching about energy transfer because, according to her, the energy unit “had a lot of hands-on that we love. [The experiments] were in the lesson plans the district gave us, and they were in the Nearpods.” Ally expressed her effectiveness at teaching about organisms on whether she felt she had enough hands-on experiments for the students.

Ally describes her least effective teaching moments when she covered topics around organisms and fossils because she does not have a lot of “fun things” to do with the students, which has made her “not feel as confident.”

**What They Say They Know Most/Least**

Erin cites living organisms as the topic she knows most about because “being a mom and having to deal with bodies” provides her with this knowledge. In addition, Erin believes this is one of the more relatable topics she teaches, as she also mentions that the students do well with this topic because of its relevance to their bodies.

According to Ally, she knows most about energy transfer because this is the topic she has taught the most, and Ally knows least about waves because she has not “spent as
much time to pull things up and help the kids understand it.”

Neither Kimmy nor Ashton was asked explicitly about topics they knew most and least about due to the time constraints of their interviews.

**Physical and Life Science Lesson Descriptions**

Erin described a life science lesson about the functions of different animal traits. Her students designed paper fingers for her lesson and developed methods to bend the fingers with string. Additionally, as part of the same unit, she wanted students to understand how eyes filter light through the retina and what people who are blind see. She concluded by having students experiment with “upside-down goggles” to observe how their bodies process information and adapt. Her lesson depiction focused mainly on what the students were doing rather than what she was doing.

When describing a physical science lesson, Erin cites sound waves as an example where she had students use ropes to try and make their own wavelengths. She had her students compare the pitch of the different waves just by looking at them with the rope formations. She said she did not have much background knowledge on this topic, prompting her to study it more prior to teaching.

Kimmy used an online resource, Mystery Science, to teach about energy. She enjoyed having the resource and mentioned it was being provided by the state this year at no cost to the elementary teachers across the state. She says she used this resource recently to have the class make a roller coaster and discuss the types of energies at different points along the roller coaster.

Ashton shared her experience teaching physical science lessons using energy and
waves as the topic. She typically uses scripted district plans that involve Nearpod presentations written by district science coaches. Within each of these lessons, Ashton follows the district-prescribed activities, such as an experiment that involves floating a duck to see wave patterns. When teaching life science, such as organisms and fossils, Ashton will more often use lessons she has modified and written over the years rather than what the district has provided. She described an example lesson where she had students compare and contrast features of fossils.

Ally described a typical physical science lesson as when she last taught energy transfer and used the district-provided and scripted presentations and activities. She remarks,

We’d go through the Nearpod presentations that have questions or activities about it. What’s good about Nearpod is they would now be able to answer questions about like what does energy transfer mean. They’d all have to type in an answer, and I can see their answers and if they understand it. After, we’d go to an experiment like one we did where you can hear cans. Students would try to hear and talk out of those for the sound to transfer through yarn. After they’d diagram in their science journals

A typical life science lesson Ally described involved more of the teacher asking questions and doing whole-class discussions. An example she gave was about the structure and function of pinecones. Ally said she struggles with topics that she doesn’t have many activities for the students to engage in. This particular topic was one she described as more direct teaching and discussion based.

**How They Develop Confidence in Teaching Science**

When asked about how she develops her confidence in teaching science topics, Erin responded:
Honestly, science has been one of the hardest ones to do before this year because I had to grab my own things. I had to research lessons. I had to put them together, and it was really hard to find really good experiments that I could do in class that really related to the topic.

For Erin, teaching confidence is developed by research and having relevant and “good experiments” to use in the classroom. In other words, Erin lacked curriculum or lessons plans, and thus relied on what she could find. Additionally, Erin mentioned that her effectiveness at teaching a topic is due to “having a good curriculum to teach and how much prep and background I have before I teach it.” Given Erin’s low SMK in science, she admits that she is aware that she lacks the “background,” which can be interpreted as PCK, to develop her own science lessons. Thus, she relies on finding activities that have worked for others.

Kimmy cited a recent summer professional development, the ability to discuss science topics with other teachers and her son, to improve her confidence in teaching science. Moreover, she argues that focusing on the areas she is confident in teaching helps her overall confidence.

Ashton’s confidence in teaching science topics stems from personal development of background knowledge and attending professional development frequently to know how to teach science.

Ally mentioned that her confidence in teaching science comes from familiarization with the standards and having hands-on or visual activities. She says that when students feel like they can do it, this adds to her confidence in teaching the topic.
Topics Difficult for Students

Erin states that the most difficult topic for students in science is learning about structures and functions of living organisms because of the large amount of accompanying vocabulary and upfront explanations before they can do hands-on.

Kimmy says she believes students struggle most with learning about energy. She reasons that this is likely due to the resources that have been used in the past to teach energy. Nevertheless, she feels like some of the online resources now available to her will assist in overcoming this learning difficulty.

Ashton finds the topics of organism structure and functions as well as energy collisions difficult for students “because they are unable to transfer the knowledge to different situations.”

For Ally, the difficult topics are the ones with fewer experiments to do and ones that include much vocabulary. Such topics include structure and function of organisms and wave patterns.

Mixed Methods Findings

When examined through a mixed methods lens the quantitative and qualitative findings converge to explicate an understanding of the relationship more richly between teacher belief and practice.

There are at least three quantitative results that can be explained through four of the major qualitative findings and demonstrate the connection between a teacher’s beliefs and classroom practices (Table 16). These three quantitative results include life STE scoring higher than physical science teaching efficacy, the positive correlation between
science SMK and STE for both disciplines, and physical science and life science
knowledge as a predictor of physical science teaching efficacy.

Table 16

Qualitative Findings that Corroborate and Explain Quantitative Results

<table>
<thead>
<tr>
<th>Quantitative finding</th>
<th>Qualitative finding</th>
<th>Example quote</th>
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<tbody>
<tr>
<td>Life Science STE higher than Physical Science STE</td>
<td>Low SMK/Low STE group relies on scripted curriculum for physical science but not life science</td>
<td>“So our district actually got a program for us this year, ... it’s just web-based and then they have the lessons, and experiment, and then they actually send us all of the supplies that you need for each unit that you’re going to teach.” - Erin</td>
</tr>
<tr>
<td>Positive correlation between SMK and STE and Physical Science SMK + Life Science SMK predict Physical Science STE</td>
<td>Most teachers claim to be more ineffective at teaching physical science topics than life science topics</td>
<td>“Least effective? Energy collisions probably. I just have to really read the material beforehand. And sometimes if a student asks a question, I have to say, ‘I have to look that up, I’m not quite sure,’ just because I haven’t really had experience with it.” - Jessica</td>
</tr>
<tr>
<td>Positive correlation between SMK and STE and Physical Science SMK + Life Science SMK predict Physical Science STE</td>
<td>Low SMK shows a reliance on scripted curriculum whereas high SMK does not (research indicates low STE teachers rely on heavily guided lessons and presentations)</td>
<td>“The district does have Nearpods that they’ve created, and so I do use those quite often, too.” - Ashton</td>
</tr>
<tr>
<td>Positive correlation between SMK and STE and Physical Science SMK + Life Science SMK predict Physical Science STE</td>
<td>Most teachers believe SMK is needed to build STE</td>
<td>“I am very confident about teaching anything I have to teach as long as I know what I’m teaching.” - Leah</td>
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</table>

Quantitative results show a significant difference between life STE and physical science teaching efficacy. Qualitative findings corroborate this result by demonstrating that teachers tend to believe they are more effective in teaching life science than physical science topics. As evidenced when participants described their least effective teaching topics as energy, waves, light, and properties of matter, which are physical science topics.
Teachers describe what they believe themselves to be poor teachers as evidence in their lack of confidence in teaching those physical science topics, further corroborating the survey finding of teachers exhibiting a lower teaching efficacy towards physical science.

Furthermore, the efficacy discrepancy by discipline affects how teachers approach their lesson preparation and what types of science activities their students engage in. Teachers with both low SMK and low STE taught physical science mentioned a reliance on district-provided resources or online curriculum for science activities and presentations. However, when these same teachers taught life science, they adapted or modified the lessons without a mention of scripted activities from the district or online (see Table 14). These accountings indicate that lower efficacy influences practice. The difference between physical and life science instructional planning and methods is apparent and can be triangulated through the demonstrated statistical difference between life and physical STE.

The least knowledgeable teachers’ descriptions of lessons that depict a reliance on district or online-provided guided activities and scripted lessons suggest a lack of confidence in their teaching abilities, supporting the statistical correlation between science SMK and STE. This connection draws from Zee and Koomen (2016) and Marshall et al.’s (2009) work that show elementary teachers with low STE tend to rely on highly guided lessons, activities, and presentations. In contrast, the finding that more knowledgeable science teachers used highly adapted and modified lesson plans establishes the quantitative finding that more science knowledge correlates to more STE. Teachers with high science knowledge and efficacy were the only group to name physical
science as their most effectively taught topic, supporting the linear model analysis that overall science knowledge predicts physical STE. Furthering the connection to the statistical model, this high SMK/high group STE also had the most coded citations of non-scripted or self-adapted lessons than any other group. The confidence of these teachers to adapt their plans to student learning needs indicates not only their teaching efficacy but also their high knowledge of life and physical science.

It is particularly noteworthy that every interviewed teacher but two claimed that more background knowledge in science content was necessary to improve their STE. This admission reveals that these elementary teachers are cognizant that science content knowledge influences their confidence in their ability to teach science. This self-awareness alone could influence STE. Moreover, given that a direct measure of disciplinary science content knowledge correlates with disciplinary STE, teachers are likely aware of their own science knowledge strengths and limitations between disciplines. This confirmed awareness infers that teachers may also be aware of the SMK and STE association that is, in fact, a statistically measured correlation.

In conclusion, survey data analysis reveals that physical science subject matter knowledge and life science subject matter knowledge are predictors of physical science personal science teaching efficacy while controlling for years of teaching and grade level. Additionally, physical science subject matter knowledge is also a predictor of life science personal science teaching efficacy while controlling for life science subject matter knowledge, years, and grade level. Evidence of physical science subject matter knowledge as a predictor of physical science personal science teaching efficacy is in the
interview responses of teachers with low physical science subject matter knowledge expressing a lack of confidence in their effectiveness in teaching physical science topics. Additionally, the interview responses show that teachers with low SMK in physical science also rely more heavily on scripted lessons and district-supplied presentations and resources when teaching physical science topics (Table 5). This reliance on these tools also indicates a lack of efficacy in their teaching ability to teach those topics. Furthermore, the quantitative analysis also demonstrates a statistically significant correlation between physical science subject matter knowledge and physical STE.

Physical science SMK and STE are statistically lower than life science SMK and STE. Further evidence of a difference between PSTE and LSTE is in the interview results. Most teachers claim they are least effective at teaching a physical science topic rather than a life science topic. When probed as to what reasons the teachers had for this belief, most teachers reported missing some needed background knowledge signaling an awareness of their lower SMK in physical science.
The purpose of this study was to examine the relationship between physical and life science subject matter knowledge and their respective subject area’s teaching efficacy. Additionally, this study investigated the difference between life science and physical science for subject matter knowledge and STE and how those differences influenced teacher beliefs and classroom practices. Finally, the study advances our knowledge about general STE by demonstrating the significant impact a teacher’s discipline-specific science knowledge has on their beliefs and instructional methods across different science topics.

The discussion that follows is organized into five segments. The first section discusses the association between discipline-specific science knowledge and STE. In the second section, I discuss the differences between life and physical science regarding a teacher’s subject area knowledge, teaching efficacy, and instructional practices. The third section presents the implications of the findings for elementary teachers, science teacher educators, and researchers. Last, in this chapter’s fourth and fifth segments, I describe the study’s limitations and suggest future research.

**Association Between Discipline-Specific Content Knowledge and Science Teaching Efficacy**

Science education literature shows a positive association between general science knowledge and STE for elementary teachers (Bleicher & Lindgren, 2005; Ely et al.,
2009; Menon & Sadler, 2016) while also presenting crucial consequences of poor instructional practices of elementary teachers with low STE (Blonder et al., 2014). While general science knowledge and efficacy associations have been examined, this study investigated the effect of individual science subject knowledge, namely life and physical science, on domain-specific teaching efficacy for each discipline.

The linear modeling analysis revealed that physical and life science subject matter knowledge predicts physical science teaching efficacy when controlling for grade and years of teaching. Surprisingly, life science knowledge does not predict life STE. However, life science knowledge positively correlates with its disciplinary teaching efficacy measure like physical science. These results corroborate the interview responses whereby only teachers with the highest physical science knowledge reported being confident in teaching physical science topics. It was unexpected to find that the linear models manifest that physical and life science knowledge predict physical teaching efficacy rather than only one subject area’s knowledge factor. This finding is likely a result of the strong positive correlation between life and physical science knowledge. This correlation may be explained by the fact that some teachers more readily adopt a science identity because of their affinity for science in general, which may be due to their previous life experiences and academic success in science (Aschbacher et al., 2010; Osborne et al., 2003). Drawing on the research of Tamir (1991), those teachers that tend to enjoy science in general, or have had many informal and formal science experiences, will likely have had more science learning success in their teacher preparation.

Knowing that disciplinary knowledge is associated with disciplinary teaching
efficacy is important because it informs teacher educators of a potential means to strengthen subject-specific elementary STE and practices by fortifying teachers’ knowledge base within that science discipline. Research shows that both teachers and students tend to find physical science, as Osborne et al. (2003) put it, “only for the intelligent and, therefore, difficult.” This misguided negative attitude impedes pre-service teachers from taking physical science courses or teaching physical science topics. Science teacher educators can help prepare future elementary teachers to overcome such subject-specific confidence obstacles through subject-specific knowledge instruction.

Given that prior research yields evidence that underscores the positive association between SMK and STE, it was unanticipated to find how little an effect size SMK had on PSTE. With 5% of the variance in physical science PSTE explained by both life and physical science SMK, one wonders what other factors might be more prominent in influencing a teacher’s efficacy. Drawing from Shulman’s (1987) work, PCK may be a factor or mediator of STE, given the correlation between SMK and PCK. Evidence of this is indicated in the statements from interviewees when they described why they feel more confident teaching specific topics over others. One of the common responses to the source of where teachers gained their confidence was because they “know how to teach it” in addition to having the necessary background knowledge. This relationship may be important to investigate in future research to understand the mediating connections between SMK and teaching efficacy.

In addition to the measured correlation between SMK and STE for each discipline, interviewed elementary teachers also reported that they believe their
knowledge of a topic influences their confidence to teach that topic. It is not just the content knowledge influencing teaching efficacy but also what Palmer (2011) says is a perception of a lack of knowledge that minimizes teacher confidence in teaching science topics. This finding supports what Capps et al. (2012) found that elementary teachers are aware of their SMK deficiencies in science. Appleton (2003) notes that teachers’ perception of not knowing science content has led some teachers to avoid teaching science topics.

Furthermore, teachers’ SMK, as measured directly through an instrument, positively correlates with personal STE for physical and life science. These findings align with previous research that used different methods to measure knowledge, such as self-reports of how much time pre-service elementary teachers spent developing content knowledge through the number of college science courses taken or interventional lessons in their methods classes (Appleton, 1995; Bleicher & Lindgren, 2005; Menon & Sadler, 2016). This finding suggests that both the teacher’s perception of knowledge level, as reported by Capps et al. (2012), and the level of knowledge itself are factors in teaching efficacy. One explanation that draws from the research by Gess-Newsome et al. (2019) is that teachers lacking science subject matter knowledge may struggle to develop and use pedagogical knowledge tools effectively. In addition, this lack of science pedagogical knowledge can influence teachers’ beliefs about how effective they are at science instruction, as Appleton (2003) reported. This finding is significant because it provides evidence that both pedagogy and content knowledge are essential for effective elementary science teaching. Furthermore, this finding informs the work of elementary
science educators and researchers, who should prioritize both areas of knowledge. This study’s SMK instrument, however, was limited in the number and types of questions used to assess knowledge. Therefore, future researchers should investigate expanded instruments to assess a broader range of scientific knowledge as it relates to science teacher efficacy.

**Differences Between Physical and Life Science Knowledge, Teaching Efficacy Beliefs, and Teaching Practices**

Results indicate that teachers’ SMK and teaching efficacy are higher in physical science than in life science. This discrepancy carries over into teachers’ beliefs and classroom practices. This study’s findings add to the literature’s previously unreported classroom teaching methods because of such differences.

For example, teachers with high science subject matter knowledge engaged in more non-scripted activities than those with lower SMK scores who rely more on district-provided curriculum and procedural activities. Much research has shown that elementary teachers with low efficacy rely on scripted procedures, or what Appleton (2003) calls “readily accessible activities.” However, surprisingly, the interview findings of this study demonstrate that the low SMK groups, not necessarily the low efficacy groups, engaged in these ineffective teaching practices. These findings suggest that teachers’ content knowledge influences their beliefs about effective teaching. Given that teachers measured lower in physical science than life science for both knowledge and teaching efficacy, it is unsurprising that the interviewed elementary teachers used different instructional
strategies for physical science topics than life science. This means students receive imbalanced lessons across science. This imbalanced practice includes teachers who avoid teaching physical science topics, likely rely on more worksheets and procedural labs than teacher-adapted inquiry activities and feel more reluctant to persist with challenges in planning and instruction. As a result, students are more likely to spend time and engage in more meaningful ways in life science than physical science.

Further, teachers with low physical science teaching efficacy were more likely to report doing these less effective teaching strategies with physical science than life science. A reliance on procedural-based lessons and district-developed presentations limits the teacher’s ability to provide science inquiry lessons adapted to students’ needs, values, and cultural identities. To learn scientific practices, students must experience them first-hand instead of merely being told what they are through second-hand instruction. Students with teachers who rely on more didactic instruction, worksheets, or the so-called “cookie cutter” lab activities, are less likely to guide students toward first-hand experiences of doing science. One primary focus of implementing NGSS is to engage students in inquiry practices of modeling, asking questions, designing investigations, and developing explanations while critiquing, evaluating, and reasoning with those explanations. Doing so piques the student’s interest and curiosity and motivates them while they come to understand how scientific knowledge forms and is rooted in evidence. For students to develop these skills and understanding, they will need teachers who are more willing to adapt and adjust lessons while also using a broad spectrum of student-centered strategies to give students experiences that use these
practices. Unfortunately, the less knowledgeable and thus less confident teacher is also more likely not to question the scripted lesson’s content or structure, leading to misinformed pedagogy or, worse, students developing unchallenged science misconceptions.

One likely explanation for why elementary teachers rely on scripted science lessons is that elementary teachers develop a broad set of pedagogical skills that need to translate across multiple subjects in the elementary school setting. Not having the content knowledge to inform pedagogical knowledge specific to science disciplines makes teaching science more difficult, creating a greater need to rely on more step-by-step lesson procedures. Elementary teacher educators who focus on teaching pedagogy without teaching content leave future teachers without specific tactics and reasons for employing topic-tailored teaching methods. Instead, teachers are left to rely on one-size-fits-all pedagogical strategies. Therefore, elementary teacher education programs and professional development should be cautious if ever prioritizing pedagogy over content knowledge to develop confident and effective future educators.

Additionally, a finding not previously reported in the literature is that teachers with high science subject matter knowledge tend to engage in more student-centered teaching approaches than teachers with lower SMK scores, who adopt a teacher-centered paradigm. This means that teachers with low scientific understanding tend to focus more on what the teacher does in the classroom than what students do. One possible reason teachers do this is that they are still trying to figure out how to carry out lessons as instructors. This finding demonstrates a lack of confidence in teachers’ ability to conduct
themselves and student activities. Teachers thinking more about what students are doing during lesson planning are more likely to prioritize student learning needs and student-inquiry science practices. Understanding how elementary teachers think through lessons is vital because the Next Generation Science Standards prioritize students practicing science skills as much as they are learning content. Such inquiry practices include engaging students in modeling, asking questions, designing investigations, and developing explanations while critiquing, evaluating, and reasoning with those explanations. Doing so piques the student’s interest and curiosity and motivates them while they come to understand how scientific knowledge forms and is rooted in evidence. For students to develop these skills and understanding, they will need teachers who are more willing to adapt and adjust lessons while also using a broad spectrum of student-centered strategies to give students experiences that use these practices. Given the connection knowledge has with efficacy, this may explain Rollnick et al.’s (2008) research findings that teachers with less SMK typically have fewer student-centered activities resulting in less student inquiry. The less knowledgeable and thus less confident teacher is also more likely not to question the scripted lesson’s content or structure, leading to misinformed pedagogy or, worse, students developing unchallenged science misconceptions. To learn scientific practices, students must experience them first-hand instead of merely being told what they are through second-hand instruction. Students with teachers who rely on more didactic instruction, worksheets, or the so-called “cookie cutter” lab activities, are less likely to guide students toward first-hand experiences of doing science. Therefore, elementary teacher education programs and professional
development should be cautious if ever prioritizing pedagogy over content knowledge to develop confident and effective future educators.

Most interviewed teachers described their favorite lesson to teach as one of the physical science topics in their standards. However, they also described a physical science topic as their least effective teaching. Teachers describe such lessons they enjoy as “fun for students.” This result means there are topics within disciplines teachers may find enjoyable, despite struggling with the discipline in general. One explanation for why these teachers enjoyed teaching physical science was that their districts provided them with guided resources, hands-on materials, increasing student engagement, and guided presentations to make the teaching accessible. Also, when the teacher had student lab materials and a step-by-step procedure laid out, the teacher was less burdened with preparation and may have found this more pleasant. As reported by the teachers, life science activities in the classroom tended to be less an interactive and hands-on experience than physical science. Regardless of which topics they enjoyed, teachers still felt least confident in their ability to help students make connections with physical science concepts amid the engaging activities. This is important because teachers who lack confidence in teaching physical science often limit their instructional time teaching it or sometimes do not teach some physical science topics. Elementary teachers who use district-provided lesson resources with scripted activity procedures may have excluded students from essential inquiry practices needed in science learning but are less likely to abandon or reduce science teaching time.

Despite the elementary teachers scoring lower in personal science teaching
efficacy for physical science than life science, teachers did score higher in their outcome expectancy in physical science. STOE measures the teacher’s belief in how much the teacher can overcome external factors to help students learn. However, teachers appear to have more confidence that students will still perform well in physical science despite their own belief that they, the teacher, perceive themselves as ineffective. The STOE subscale measures how much the teacher plays a role in student performance. The teacher participants indicated that the student’s performance in life science would generally result from the teacher’s performance more than in physical science.

STOE is also a measure of how the teacher believes their effectiveness influences the student’s learning and how much that effectiveness can overcome challenges to the learning. For example, a teacher with high physical STOE believes “the teacher is generally responsible for the achievement of students in physical science” (item 14 on STEBI-A). A participant who reads this side-by-side with the physical science version and agrees with the statement perceives the student’s success or failures as a product of the teacher’s capabilities in teaching physical science. Thus, the teacher holds themselves accountable for the student’s success or failure in learning physical science. Elementary teachers consider themselves less effective at teaching physical science topics while believing they are responsible for how well that student learns physical science, more so than life science. Prior studies have not observed this relationship between physical science STOE and life science STOE. It is likely that the teachers either believe the students are more likely to learn or not learn life science regardless of the teacher or that they have less influence on student performance in physical science than in life science.
Implications

This study provides a contribution to STE research by demonstrating the nuanced differences in SMK and efficacy within and across physical and life science. Elementary teachers tend to have more knowledge and thus teach efficacy toward life science than physical science. This imbalance in disciplinary knowledge and efficacy manifests in patterns expressed in teachers’ beliefs as well as instructional planning and implementation.

Because physical and life science subject matter knowledge is predictive of physical science teaching efficacy, there is a critical need to train teachers on discipline-specific content knowledge while simultaneously developing discipline-specific teaching efficacy. Some teacher educators may claim that SMK comes over time with experience and that the effects of SMK are negligible compared to PCK. However, this study demonstrates that discipline-specific SMK is vital to a teacher’s needed knowledge base because that knowledge influences teaching efficacy and instructional practices toward specific science topics.

This difference in content knowledge and efficacy between life and physical science results in dramatic teaching differences and is notable across the lifespan of a teacher’s career. For example, this study indicates that teachers with low physical science knowledge rely on rote procedural activities and teacher-centered lesson planning and instruction. As a result, teachers are less likely to adapt to diverse student learning needs or engage students in inquiry, modeling, student-developed experiments, and other NGSS science and engineering practices. These behaviors deprive students of learning
experiences in the physical sciences and engage them less in essential scientific practices. Without a strong foundation early in physical science, students will lack the tools they need to understand and investigate complex ideas across science topics and future grades. To overcome this dire outcome, higher education institutions, districts, and schools will need to find ways to build teacher content knowledge and efficacy in specific science disciplines rather than treating science as a single subject. This behavior contrasts with teachers who reported higher efficacy and described their lessons as more about what the students were doing. Examples of these student-centered descriptions included creating a growing table for students to test various experiments with plants and creating a model for how the eye receives information through light. In these examples, teachers did not mention the reliance on rote procedures or worksheets provided by outside sources. Instead, they adapted and developed their lessons from various sources because of their confidence in their ability to teach those life science topics.

This study extends teaching efficacy research by demonstrating that elementary teachers perceive themselves as less effective at teaching physical science while simultaneously believing their ineffectiveness can influence students’ physical science achievement more than life science. The consequences of these beliefs and varying levels of SMK are far-reaching, directly influencing students. These ramifications include students having fewer opportunities to engage in inquiry-based practices, teachers avoiding challenging science questions from the students while possibly neglecting challenging topics, and teachers relying on only materials the district, or other outside sources, provided to teach specific topics. However, these actions, or inactions, are not
enacted evenly across subjects within science but, instead, unevenly in favor of the topics teachers are more confident and knowledgeable about, such as life science.

**Recommendations**

Given the consequential need to close the gap between life and physical science knowledge and teaching efficacy for elementary teachers, I recommend pre- and in-service adjustments. It is essential to recognize in light of the findings of this study that when a teacher knows less about one subject area, they are more likely to have less confidence and thereby implement ineffective science teaching methods in their classroom for that discipline. Thus, an imbalance of science topic learning during a teacher’s college preparation years can be considered not merely lopsided but incomplete and consequential.

**Science Methods Instructor Recommendations**

Because many elementary science methods instructors were previously elementary teachers, and the last three decades of elementary education research show a discrepancy between life and physical science knowledge, instructors may be partial towards life science topics over physical science. Science methods instructors should evaluate and adapt their course curriculum based on pre-assessments of their students’ understanding of relevant science content knowledge to avoid planning course curricula with partiality. Methods instructors can also demonstrate to their students the interdisciplinary nature and need of science concepts so that their students may learn the relevance of teaching complete standards. Methods courses can teach effective
instructional strategies while filling in gaps to strengthen the limited areas within science disciplines.

**District Recommendations**

District leaders and instructional coaches should provide elementary teachers with professional development geared toward instructional strategies and discipline-specific SMK and efficacy. Research indicates that when professional development coupled disciplinary content learning with attitude reflections about teaching discipline-specific content, teaching confidence improved (Nilsson & van Driel, 2011).

Furthermore, district leaders should provide specialized science content instructional coaches in science to teachers for instructional support, given that they can be highly effective in tailored subject-specific training (Desimone & Pak, 2017). These instructional coaches can show teachers how more widely used inquiry-based and current NGSS science and engineering practices (SEP) can help students develop well-rounded content knowledge across disciplines. As instructional coaches also engage teachers in inquiry-based science experiences that incorporate the SEPs, elementary teachers can develop gains in their science content understanding alongside teaching confidence toward discipline-specific content (Avery & Meyer, 2012). This study’s interview data suggests that students and less knowledgeable science teachers find physical science topics challenging because of the content’s abstract nature. Instructional coaches can engage elementary teachers in SEP-based activities to provide more sense-making with abstract and complex ideas, making physical science concepts more approachable for teachers and students alike.
One of the common practices that the low SMK group of teachers had in common was the reliance on district-provided resources, especially in physical science. These resources included equipment and a step-by-step curriculum. Some of these teachers mentioned that they enjoyed teaching physical science because of the accessibility and ease of use of these resources. However, they also claimed they would skip over teaching the concept if they did not know enough about the topic or how to teach it. Therefore, districts must supply teachers with plenty of curriculum and equipment resources to allow teachers access to a wide range of physical science activities and topics that otherwise would not be taught if missing.

**Limitations**

No study is without limitations. The qualitative findings address the teachers’ understandings and beliefs about their knowledge and efficacy sources. However, self-report data is known to be limited in accuracy (Stone et al., 1999). Their descriptions of how they teach are not purely indicative of how they, in reality, teach in the classroom. At any end of the efficacy spectrum, teachers may show bias in their reported descriptions. For example, teachers may exaggerate their practices in the classroom based on what they attempted to do but experienced less success than they reported. The reliance on self-report data for the qualitative portion of the data collection and analysis also limits the analysis to only the teacher-reported practices. Memory bias can affect the reported activities and behaviors in the classroom. As a result of the teacher’s distant memory at the time of the interview, some teachers may exclude or include behaviors and
instructional methods they remembered doing but, in actuality, did not.

Given that there were eleven interview participants for this study and only a few within each category, results are limited in making generalizable statements about any one category of SMK or STE for teachers at-large based on participant comments. With this in mind, it is essential to recognize their reports’ exploratory and explanatory nature with the need for further investigation in future studies. Further, not all interviews were conducted under the same time conditions based on the participant’s schedule while doing the interview online (though all were between 15-25). With some interviews being slightly shorter, teachers may have given less information, while others may have provided more information.

Further limitations to this study include the breadth of science content used in the SMK questions. A set of only ten questions does not generalize to an accurate level of the teacher’s knowledge in any particular subject. However, a few questions afforded a more practical approach to gaining a higher survey response. The amount of teaching experience with the new state standards varied by district and teacher. This was partly due to the state implementing the science teaching standards three years prior to this study. Also, some of the standards carried over from the previous standards, while some were entirely new. The survey did not account for the teacher’s familiarity with their standards. Nevertheless, this study restricted the survey to teachers who had at least taught for one year, with 95% of the participants reporting more than three years of teaching experience.

Another limitation of the study would be the sample size. While the sample size
procured for the study was sufficient to power the statistical analysis, the small effect size and accounting for variance indicate that a larger sample size may show different results. In addition, as the sample size increases, so do the accuracy of the effect size of $R^2$ and the ability to generalize the model to a larger population.

Last, the study is limited in its ability to measure SMK coverage for all of any one discipline within a set of teaching standards. Teachers cited various topics within their teaching standards as responses to the interview questions. However, these topics are not all addressed equally within the survey’s SMK questions for each discipline. With the survey taken online, time constraints accompanied this study to increase the chance of participation and survey completion. Thus, only ten questions for each discipline were reasonable for the survey. However, ten questions cannot account for each science teaching standard’s variety and depth. A more accurate knowledge assessment would involve a survey with more question coverage of the breadth and depth of each standard.

**Future Research**

Given the small variance observed in personal science teaching efficacy predicted by SMK, I recommend that future studies include means to investigate potential mediators of discipline-specific SMK and STE, such as PCK by discipline. Interviewed teachers in this study reported that their confidence stems from background knowledge, but some teachers added that knowing how to teach is also consequential to their teaching efficacy. Many pedagogical decisions rely on how well the teacher understands the disciplinary core ideas of what they teach. In order to examine the impact of discipline-
specific knowledge on a teacher’s pedagogical knowledge, researchers will need to
develop the means by which they can measure discipline-specific pedagogical
knowledge. If anything, research can include what discipline-specific pedagogical
decisions teachers make because of SMK levels per discipline.

There is a real need to understand what is currently being done at both the pre and
in-service levels of teaching to help teachers with their discipline-specific knowledge and
teaching efficacy. Questions for inquiry include: What is being done in teacher
preparation classes to assist pre-service teachers in learning their teaching standards’ core
ideas? Are there subject-specific topics that receive more attention than others in teacher
preparation programs? Following the trajectory from pre-service to in-service teaching,
what ongoing professional development is in place to continue building off the scientific
knowledge teachers bring? What resources, curriculum, and conditions are needed to
sustain teachers’ learning of subject matter over time? How willing are in-service
elementary teachers to participate in professional development about SMK, and does this
change longitudinally in their career?

The literature is rich in studies investigating pre-service teachers’ STE and
general science subject matter knowledge. In contrast, science teacher educators may
assume in-service teachers are more resistant to improvement in efficacy across their
career life than pre-service teachers. Understanding what influences the in-service
teachers’ STE will ultimately offer insight into where district and college-level
institutions can focus their efforts to improve efficacy. There is a need for future studies
to investigate in-service teacher factors that impact discipline-specific personal science
teaching efficacy, given the significant differences between life and physical science and their impact on teaching practices. Very few studies have examined what contributes the most to a career teacher’s subject-specific STE.

Also, there are few SMK inventory questions adapted to elementary teachers for specific science subject areas. It is recommended that future studies develop and test a new set of concept inventories that address more concepts found within the next generation of science standards. In order to properly assess the breadth or depth of knowledge a teacher has, the science education field will need a more robust set of inventories to measure knowledge. These concept inventories should target uncovering common misconceptions of today’s generation of students and teachers.

To investigate beyond the self-reported practices from this study, researchers will want to examine the science teaching practices of in-service elementary teachers in the classroom and compare the practices of those teachers who measure high on the subscales of STEBI-A with those who measure lower. Investigative questions include: What kinds of science activities do teachers with varying levels of efficacy provide their students with? Do differences in practices exist between the different science disciplines? How much time do teachers spend teaching each of the sciences within their standards, and are they balanced?

One of the more prominent looming questions is why there have been persistent differences in teacher efficacy between physical and life sciences throughout the past three decades (Akerson, 2005; Al Sultan et al., 2018; Appleton, 2003; Harlen & Holroyd, 1997). To uncover this, researchers will want to look for influential factors that prevent
teachers from being interested in choosing physical science college courses over life science courses. Are influential factors for pre-service teachers the same for in-service teachers? For example, several interview participants claimed that life science is much “more relevant to everyday life” than physical science. This perspective offers a glimpse into why teachers might focus their teaching energy on one topic more than another or why a pre-service teacher may choose elective life science courses over physical science. It is unclear what other factors might also cause teachers to aim for learning or teaching only topics of interest that they deem most relevant. If such influential factors navigate the teacher away from a science discipline, are there methods to overcome their effect? Are in-service teachers offered professional development in both sciences and choose to ignore the ones they believe are less relevant to their students because they are less relevant to them?

Conclusions

This study’s findings and prior studies show that elementary teachers need additional professional development in physical science content knowledge and teaching efficacy. Elementary teachers are more susceptible to relying on less effective strategies without improving SMK and teaching efficacy in physical science. These ineffective teaching methods include scripted presentations involving more didactic instruction instead of inquiry-based activities. Teachers are also less likely to give the same amount of instructional time as they would more efficacy-favored topics.

As a science education research community, we must continue to recognize that
elementary teachers’ science SMK, pedagogical knowledge, and teaching efficacy grow the fastest during pre-service teaching years because of their formal educational experiences. However, teacher learning should not end there, as in-service teachers can enhance their knowledge and efficacy via professional development and endorsement programs throughout their teaching career (Lumpe et al., 2012). With this understanding, educational institutions are also accountable for why elementary science teachers demonstrate a knowledge difference gap and lower personal science teaching efficacy in physical science than in life science. Thus, the science education community is also responsible for closing this subject-specific knowledge gap and teaching efficacy discrepancy between life and physical science.

Science at the elementary level has often been treated as a singular subject, though science comprises multiple discipline-specific teaching standards. The literature and this study demonstrate that these standards are not treated evenly by the teacher in the classroom concerning the amount of instructional time, the style of instruction delivery, and the types of implemented student activities with each standard. This unequal instruction is primarily due to a teacher’s different levels of STE per discipline. Such asymmetrical teaching leads to asymmetrical learning by the students. Life science continues to lead as the subject area where teachers have the most efficacy towards teaching and content knowledge compared to physical science. There are significant intersections between each discipline in science. A portion of these intersections was named as a crosscutting concept and implemented into the next generation science standards, namely energy. Like many other cross-subject topics, students who understand
the physical science aspects of energy can better comprehend a litany of phenomena found across disciplines. This cross-integration of topics from multiple science disciplines helps students develop better models of nature, becoming more scientifically literate. To achieve higher levels of student science literacy, science educators must work to improve the discrepancy between life and physical science found in STE and SMK of elementary teachers. As the literature points out, elementary teachers can overcome the gap in efficacy or knowledge for each subject area through subject-targeted in-service training.
REFERENCES


APPENDICES
Appendix A

Recruitment Emails
Initial Survey Recruitment Email

Dear Teacher,

You’ve been selected as a 4th or 5th grade elementary teacher to participate in a study conducted by Utah State University examining beliefs about teaching science in elementary schools. If you choose to participate, you will be entered into a raffle drawing with 1 in 6 chances of winning a $50 amazon gift card. The study can be completed through an online survey within about 30-45 minutes. Any information you provide will remain completely confidential. The results of this study will be used to understand how to better assist elementary teachers who teach science. If you are interested in participating, click the link below. If you received this email in error, we apologize and ask if you could forward this email to your 4th and 5th grade teacher colleagues. Thank you!

Qualtrics Online Survey Link

Interview Recruitment Email

Dear [NAME],

You’ve been selected as a [4th or 5th] grade teacher to participate in a brief 15-20 minute follow-up interview via Zoom because of the USU Survey on Science Teaching Beliefs that you completed in December. Upon completion of the zoom interview, you will receive a $10 Amazon gift card by email. If interested, please sign up for a time slot for next week [WEEK DATES] using the link below to view times available. If you are uninterested in participating, please let me know so that I can give your slot to another survey participant. If there are questions, please let me know. Thank you!

Interview Time Slot Sign-up:

Link
Appendix B

Subject Matter Knowledge Survey Questions
PHYSICAL SCIENCE

1. Sue sticks one end of a metal rod into a box filled with ice. The end of the rod that is covered with ice becomes cold. After a while Sue places her hand on the upper end of the rod outside the box and feels that it is cold. What do you think has happened?
   a. Cold has transferred from the lower end of the rod to the upper end.
   b. The rod gave up heat to the ice.
   c. Cold moved from Sue’s hands towards the rod.
   d. Heat moved from the rod to Sue’s hand.
   e. It depends on the original temperature of the rod.

2. A solid red block and a solid green block of the same size are placed in a container of water. The red block floats and the green block sinks. From this you know that:
   a. the two blocks are made of the same material.
   b. the red block is heavier than the green block.
   c. the green block is heavier than the red block.
   d. the two blocks weigh the same.
   e. You cannot say anything else about the blocks.

3. When a thrown baseball reaches the top of its path (see below), the main push or pull acting on it is:
   a. caused by Earth’s magnetic field.
   b. the force from the person throwing it.
   c. due to Earth’s rotation.
   d. the pull of gravity.
   e. No force is acting on the ball.

4. What is true about the source of any sound?
   a. A living thing had to be involved.
   b. Something had to vibrate.
   c. Air had to be involved.
   d. More than one of the above.
   e. None of the above.
5. Zahra is sitting in her backyard, looking at a tree. With which of the following statements about how she is able to see a tree do you agree?

a. Light from her eye reaches the tree and she sees the tree.
b. Light from the Sun reaches the tree and then her eye and she sees the tree.
c. Light from the Sun reaches her eye and she sees the tree.
d. Light from her eye reaches the Sun and then the tree and she sees the tree.
e. Light from the tree reaches the Sun and then her eye and she sees the tree.

6. If you cut a bar magnet in half, each half will:
   a. no longer attract objects.
   b. attract from both ends.
   c. attract objects only at one end.
   d. have two north poles or two south poles.
   e. be more powerful than the original.

7. The first stack of bricks (stack 1) below is four times taller than the second stack (stack 2). Which stack is being pushed on harder by the table?

a. The table pushes harder on stack 1 than stack 2.
b. The table pushes equally on both stacks.
c. The table does not push on either stack.
d. The table pushes harder on stack 2 than stack 1.
e. It depends upon how closely the bricks are packed.
8. A person claims that diamonds and the graphite in an ordinary pencil are made of the same material. A scientist’s response would be that the claim is:

a. False. The two substances are too different to be made of the same material.
b. False. Every substance is unique; no two substances are made of the same material.
c. Not able to be answered with the information given.
d. True. The substances look different because what’s inside them is arranged differently.
e. True. The material is held together by a different substance, causing the different properties.

9. Suzanne is baking a cake and has placed several ingredients on the countertop to use. She has scooped some baking soda into a measuring spoon. She accidentally knocks over a cup of vinegar and several drops spill onto the spoon with the baking soda. The baking soda begins to fizz where the vinegar spilled on it. When the fizzing stops, Suzanne notices that about half of the baking soda in the spoon is gone and there is now a liquid on the spoon. The baking soda “disappeared” because it:

a. melted.
b. combined with the vinegar and produced a new liquid.
c. dissolved in the vinegar, but is still in the liquid.
d. evaporated.
e. was pushed off of the spoon by the fizzing.

10. Someone claims to have invented a system that converts sound energy into electrical energy. The inventor plans to put this system into a CD player so that the CD player’s own sound can be used to recharge the CD player’s own batteries. What do you think will happen when this CD player system is tested?

a. The system should work fine, allowing unlimited running time for the CD player.
b. The system will work, but the CD player’s volume will have to be kept in a narrow range, not too low, not too loud.
c. The system will work, but the CD player’s volume will vary from low to high depending on whether or not the battery is being charged.
d. The system will be limited by the design of the battery: if it takes too long to fully charge, the battery may go dead.
e. The system will not work and the CD player will stop working after the battery is fully discharged.
LIFE SCIENCE

1. A large tree is struck by lightning and it comes crashing down. What will happen to that dead tree after 100 years?
   a. The tree will remain there unless someone moves it.
   b. The tree will remain there forever.
   c. The tree may come back to life after a long period of time.
   d. The tree will be broken down by bacteria and fungi.
   e. The tree and all its parts will disappear forever.

2. During the winter, a brown bear will most likely react to the colder temperature by:
   a. finding a safe place to stay for the whole winter.
   b. making friends with a human family that will feed and shelter it for the winter.
   c. finding or making a warm winter coat for itself.
   d. following birds to a warmer place for the whole winter.
   e. deciding to make its fur thicker and warmer.

3. Over time, a small tree surrounded by sunflowers grows into a large tree with leafy branches that hang over the sunflowers. What will the sunflowers most likely do as the tree’s leafy branches block out more and more sunlight?
   a. Grow as large as the tree to compete for sunlight.
   b. Learn to live without sunlight.
   c. Move to a place where there is more sunlight.
   d. Climb up the tree and live on its branches.
   e. Begin to grow more slowly.

4. Seeds develop from which part of a plant?
   a. Stem
   b. Root
   c. Leaves
   d. Flower
   e. Branch

5. In a forest, which of the following are decomposers, organisms that use waste and dead organisms for food?
   a. Only the trees.
   b. Only the squirrels.
   c. Only the mushrooms.
   d. Both the trees and the squirrels.
   e. Both the trees and the mushrooms
6. Given the food chain shown below, what energy would be available to the wolf?

- a. All of the energy from the Sun, grass and deer.
- b. All of the energy from the Sun and grass, minus the energy in the deer.
- c. All of the energy transferred from the Sun to the grass.
- d. Only the energy contained in the grass.
- e. Some of the energy transferred from the Sun to the grass to the deer.

7. A pond ecosystem is best defined as:
   - a. only the animals that live in the pond.
   - b. only the plants that live in the pond.
   - c. only the water in the pond.
   - d. both the living and the non-living things in and around the pond.
   - e. both the animals and the plants that live in and around the pond.
Appendix C

Physical Science Teaching Efficacy Belief Instrument
Please indicate the degree to which you agree or disagree with each statement below by circling the appropriate letters to the right of each statement.

SA = Strongly Agree
A = Agree
UN = Uncertain
D = Disagree
SD = Strongly Disagree

1. When a student does better than usual in physical science, it is often because the teacher exerted a little extra effort
   SA A UN D SD

2. I am continually finding better ways to teach physical science.
   SA A UN D SD

3. Even when I try very hard, I don't teach physical science as well as I do most subjects.
   SA A UN D SD

4. When the physical science grades of students improve, it is most often due to their teacher having found a more effective teaching approach.
   SA A UN D SD

5. I know the steps necessary to teach physical science concepts effectively.
   SA A UN D SD

6. I am not very effective in monitoring physical science experiments.
   SA A UN D SD

7. If students are underachieving in physical science, it is most likely due to ineffective physical science teaching.
   SA A UN D SD

8. I generally teach physical science ineffectively.
   SA A UN D SD

9. The inadequacy of a student's physical science background can be overcome by good teaching.
   SA A UN D SD

10. The low physical science achievement of some students cannot generally be blamed on their teachers.
    SA A UN D SD

11. When a low achieving child progresses in physical science, it is usually due to extra attention given by the teacher.
    SA A UN D SD

12. I understand physical science concepts well enough to be effective in teaching elementary physical science.
    SA A UN D SD

13. Increased effort in physical science teaching produces little change in some students' physical science achievement.
    SA A UN D SD

14. The teacher is generally responsible for the achievement of students in physical science.
    SA A UN D SD

15. Students' achievement in physical science is directly related to their teacher's effectiveness in physical science teaching.
    SA A UN D SD

16. If parents comment that their child is showing more interest in physical science at school, it is probably due to the performance of the child's teacher.
    SA A UN D SD

17. I find it difficult to explain to students why physical science experiments work.
    SA A UN D SD

18. I am typically able to answer students' physical science questions.
    SA A UN D SD

19. I wonder if I have the necessary skills to teach physical science.
    SA A UN D SD

20. Effectiveness in physical science teaching has little influence on the achievement of students with low motivation.
    SA A UN D SD

21. Given a choice, I would not invite the principal to evaluate my physical science teaching.
    SA A UN D SD

22. When a student has difficulty understanding a physical science concept, I am usually at a loss as to how to help the student understand it better.
    SA A UN D SD

23. When teaching physical science, I usually welcome student questions.
    SA A UN D SD

24. I don't know what to do to turn students on to physical science.
    SA A UN D SD

25. Even teachers with good life science teaching abilities cannot help some kids learn physical science.
    SA A UN D SD

Appendix D

Interview Questions
1. What are some of your favorite topics to teach in science and why?

2. Which topics in the science teaching standards do you feel you are most effective at teaching? Least effective?
   a. Walk me though how you typically teach [effective topic] and [least effective]?
   b. What do you think makes you effective at teaching that topics?

3. How have you developed confidence in teaching those science topics?

4. Which topics in the science teaching standards do you feel you know the most about? Least about?
   a. Why do you know more about __________?

5. Think back to a lesson on [insert life science strand]. What were some of the ways you taught [insert life science strand]?

6. Think back to a lesson on [insert physical science strand]. What were some of the ways you taught [insert physical science strand]?

7. Which of the science standards do you think are most difficult for the students to learn?
   a. What makes these topics difficult for students to learn?

8. What do you do in your lesson planning and teaching when you come across a science topic you don’t know much about but still need to teach?
   a. What do you do in class when a student brings up a topic that you don’t know much about? … asks a question you don’t know much about?

9. Anything else I should know about your experiences in teaching science?
Appendix E

Informed Consent Form
Exploring the Science Teaching Beliefs of Elementary Teachers

You are invited to participate in a research study by Doug Ball, a Ph.D. Candidate, and Dr. Colby Tofel-Grehl, an Associate Professor, both of the School of Teacher Education and Leadership at Utah State University.

The purpose of this research is to understand the science teaching beliefs of elementary teachers. Specifically, we are interested in beliefs about science teaching confidence and content knowledge for life and physical sciences. You are being asked to participate in this research because you are a qualified 4th or 5th grade teacher with at least 1 year of teaching experience.

Your participation in this study is voluntary and you may withdraw your participation at any time for any reason. Withdrawing can be done through exiting the survey by closing the web browser at any time, or by requesting to stop an interview at any time. All data collected will be deleted for any participant who chooses to withdraw. We will not be able to remove participants once data has been stripped of any identifiable information. Participants will not be removed from the study unless they choose to withdraw by the aforementioned methods above or by contacting one of the researchers listed below.

If you take part in this study, you will be asked to take two separate online surveys. The first survey is about science teaching confidence which lasts 10 minutes and the other survey is about your content knowledge of life and physical science which lasts about 30 minutes. Your total participation in this project is expected to be 40 minutes. You may be invited to participate in a follow-up interview about your survey responses and is completely voluntary. If you choose to participate, the interview will last about 15 minutes and will take place via the Zoom video conferencing platform online or by phone.

The possible risks of participating in this study include:

- Discomfort answering questions about your teaching confidence or content knowledge.
- Loss of confidentiality. We remove or change all personally identifying information to protect privacy. We will also keep all data secure in offices at Utah State University and will not share it outside of the research team.

The benefits of participating in this study include:

- Increased awareness about your beliefs towards teaching science subjects
- Increased awareness about your content knowledge
- Although not a benefit to you, this study will benefit researchers in understanding science teaching beliefs and content understanding for specific science subjects.

We will make every effort to ensure that the information you provide remains confidential. We will not reveal your identity in any publications, presentations, or reports resulting from this research study.

We will collect your information through Qualtrics and potential video recordings of interviews (for those selected and choose to participate in follow-up interviews). Online activities always carry a risk of a data breach, but we will use systems and processes that minimize breach opportunities. Any personal information, survey results, and video recordings will be securely stored in a restricted-access folder on Box.com, an encrypted, cloud-based storage system and on an external hard drive in a restricted-access office secured with a key code and key lock on the door. All identifiable information will be destroyed within 4 months of interviews.

School of Teacher Education and Leadership | teal.usu.edu | 2805 Old Main Hill | Logan, UT 84322
For your participation in this research study you will be entered into a drawing to win a $50 Amazon gift card. You will only be entered into the drawing one time upon completion of both surveys. The drawing will take place within two weeks of the survey close date. Winners will be notified by email. Those individuals invited to participate in the interview process will each be compensated with a $10 Amazon gift card in addition to their names being part of the $50 Amazon gift card drawing.

You can decline to participate in any part of this study for any reason and can end your participation at any time.

If you have any questions about this study, you can contact

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Principal Investigator
Associate Professor
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Thank you again for your time and consideration. If you have any concerns about this study, please contact Utah State University’s Human Research Protection Office at (435) 797-0567 or irb@usu.edu.

By continuing to the survey you agree that you are 18 years of age or older and wish to participate. You agree that you understand the risks and benefits of participation, and that you know what you are being asked to do. You also agree that if you have contacted the research team with any questions about your participation and are clear on how to stop your participation in this study if you choose to do so. Please be sure to retain a copy of this form for your records.
CURRICULUM VITAE

DOUGLAS BALL
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Education

Ph.D., Science Education (Expected December 2022)
Utah State University, College of Education & Human Services, Logan, UT

Utah State University, College of Education & Human Services, Logan, UT

B.S., Physics (May 2012)
Utah State University, College of Science, Logan, UT

Research

Utah State University, Logan, UT (Oct. 2017 – Present)
CHAOS Learning Lab, Graduate Research Assistant

- Investigations include exploring relationship between subject matter knowledge and science teaching efficacy of elementary teachers, how teachers learning nature of science through apprenticeship-like research experiences, student conceptualization of physics through physics escape room puzzles. Advisor: Dr. Colby Tofel-Grehl

Utah State University, Logan, UT (Oct. 2009 – May 2012)
Materials Physics Group, Undergraduate Researcher

- Analyzed time-dependent cathodoluminescence and electron transport behavior in highly disordered polymeric materials. Mentor: Dr. JR Dennison

Yale University, New Haven, CT (June 2011 – Aug. 2011)
Center for Research on Interface Structures and Phenomena (CRISP) Undergraduate Research Fellowship

- Developed proof of concept for an oxide-semiconductor (BTO-Ge) thin film device for use in photocatalytic hydrogen production from water. Mentor: Dr. Fred Walker

Utah State University, Logan, UT (Oct. 2007 – Feb. 2009)
Undergraduate Researcher

- Analyzed semiconductor (InGaAs) nanodot formations using Scanning Tunneling Microscopy. Mentor: Dr. Haeyeon Yang
**Peer-Reviewed Journal Publications**


**Published Conference Proceedings**


In *Proceedings of the 7th Annual Conference on Creativity and Fabrication in Education* (article 2). New York: Association for Computing Machinery (ACM).

**Conference Presentations**


1. **Ball, D.** Slansky, J., *Appealing K-12 Demonstrations to Inspire Students with Physics*, Poster, Quadrennial Congress of Sigma Pi Sigma, Fermilab, Batavia, IL, 2008

**University Teaching History**

**Fall 2020:** Utah State University TEAL, Logan UT - Instructor  
*SCED 3400/SCED 5820: Teaching Science: Methods* (3 credits)

**Summer 2018:** Utah State University TEAL, Logan UT - Instructor  
*TEAL 6560 KTI: Energy In STEM: STEM Endorsement Course* (3 Credits)
Spring 2018: Utah State University TEAL, Logan UT - Instructor
*TEAL 6560 KT1: Energy In STEM: STEM Endorsement Course (3 Credits)*

Fall 2018: Utah State University TEAL, Logan UT - Teaching Assistant
*SCED 3400/SCED 5820: Teaching Science: Methods (3 credits)*

Fall 2017: Utah State University TEAL, Logan UT – Instructor
*SCED 3400/SCED 5820: Teaching Science: Methods (3 credits)*

Professional Development Teaching Experience

Fall 2019 – Present: District Physics Teachers Team Lead
Davis School District, Farmington, UT
Instruct physics teachers across district and lead district-wide collaborative efforts

Summer 2018: Electronic Textile (STITCH) Workshop Instructor
Utah State University, Logan, UT
Taught over 80 K-12 teachers in STEM integration with electronic textiles

Summer 2017: Electronic Textile (STITCH) Workshop Instructor
Utah State University, Logan, UT
Taught over 30 K-12 teachers in STEM integration with electronic textiles

Awards and Honors (*indicates undergraduate research grants)

- College of Education and Human Services Student Research Award (2021)
- Davis School District Teacher of the Week (2020)
- Utah State Board of Education Science Standards (SEEd) Physics Writing Committee Member (2018)
- Utah Retired Teachers Association Scholarship Recipient (2018)
- Yale University, Center for Research on Interface Structures and Phenomena, Summer Undergraduate Research Fellowship (2011)
- American Physical Society Four Corners Section Meeting Best Presentation Award (2011)
- David and Terry Peak Outstanding Achievement in Physics Award (2011)
- *USU Undergraduate Research and Creative Opportunities Grant Recipient (2011)
- USU College of Science Questar Scholarship (2009)
- *USU Undergraduate Research and Creative Opportunities Grant Recipient (2008)

K-12 Teaching Experience

Physics and AP Physics Teacher (8/14-Present)
Syracuse High School, Syracuse, UT
Physics Teacher (8/12-12/14)
Catalyst Preparatory Academy, Brigham City, UT

Peer Reviewer

- Association for Science Teacher Education International Conference
- National Association of Research for Science Teaching International Conference
- International Society of the Learning Sciences Conference
- FabLearn International Conference